BRITISH (TERRA NOVA) ANTARCTIC EXPEDITION
1910--1913

DETERMINATIONS OF GRAVITY

BY

C. S. WRIGHT, O.B.E., M.C., B.A. (RESEARCH, CANTAB.), M.A. (TORONTO), F.R.A.S., F.INST.P.

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PENDULUM OBSERVATIONS.

It was early decided by Captain Scott, on the advice of the late Professor Helmert of the *Central Bureau für Erdmessung*, that further pendulum observations should be made in continuation of the work in the Antarctic by L. Bernacchi, of Captain Scott's former "Discovery" Expedition, and of Professor von Drygalski, the leader of the German Expedition of 1901.

By the kindness of the late Professor Helmert, the loan was offered of the necessary apparatus from the Potsdam Geodetic Institute. Early in June, 1910, therefore, I proceeded to Potsdam in order to gain experience in the use of the instruments under the able tuition of Professor L. Haasemann. Thanks, again, to the efforts of the late Professor Helmert and Professor Haasemann, who had already standardized the apparatus and found its constants, I was able to complete the necessary observations and return with the apparatus in time to catch the "Terra Nova" at Cardiff.

On the journey to Cardiff, the apparatus was treated with the greatest care, since any serious variations in length of the pendulums (due, for instance, to sudden shocks), would be almost fatal to accurate work. The pendulums are peculiarly liable to such shocks when travelling by rail and, wherever possible, it was customary to travel by boat in order to avoid these disturbances. After leaving Cardiff. no rail journey of more than about 6 miles length was undertaken until the pendulums had completed their work in the South. On the return, however, it was found necessary to bring the apparatus across Canada *via* the Canadian Pacific Railway, but, thanks largely to the kindness of their officials in Vancouver and elsewhere, all the pendulums accomplished the journey without mishap.

The list of those, exclusive of Captain Scott, Dr. Simpson and other members of the Expedition, to whom I am indebted for valuable help and assistance, is indeed a long one.

First and foremost comes Professor Helmert, by whose efforts the observations were made possible, and Professor Haasemann, who gave up so much time to the standardization of the apparatus and so ably coached me in my first observations. To Professor Schnauder also, for coaching and valuable advice on time observations for clock rate, my best thanks are due.

In New Zealand, I have to acknowledge the loan of instruments by Dr. C. C. Farr. of Christchurch, while to Mr. H. F. Skey, Director of the Magnetic Observatory, I am indebted not only for instrumental aid, but also for much valuable time and personal help in the setting up and working of the pendulum apparatus and of the transit instrument at Christchurch.

I am indebted, generally, also to the Government Railway officials in New Zealand, and to the officials of the Government Telegraph Service in particular, for the use of a direct cable line from Christchurch to Wellington while rating the clock at Christchurch from the Hector Observatory. Not least am I indebted to the sympathetic attitude of the Prime Minister and the Hon. H. D. Allen, without which little could have been done. Most of all, I have to thank Mr. C. E. Adams, Government Astronomer of New Zealand, who took many of the necessary observations in New Zealand, reduced them, and lent other valuable assistance, and Professor T. H. Laby for the loan of a large induction coil and other apparatus, and for valuable help at odd hours of the night.

In Australia, the list of those to whom I am indebted is hardly less large. This includes Professors Pollock and Sir Edgeworth David in Sydney and Professor Lyle, Mr. Baracchi and Mr. Merfield at Melbourne. In particular, I have to thank Mr. Merfield for taking and reducing the necessary time observations for rating the clock.

Lastly, but by no means leastly, I have to thank Captain F. P. Evans of the Union Steamship Company for the care and trouble taken in the stowage of the instruments on their voyage from Australia to San Francisco.

The Pendulums.

The apparatus lent by the Central Bureau at Potsdam was of Colonel von Sterneck's pattern,*—three half-second invariable pendulums and one variable auxiliary pendulum, each swinging from its agate knife-edge on a separate agate plane.

The observing pendulums supplied were numbered 5, 7 and 21. Of these, No. 21 was of brass by Stückrath, No. 7 of brass by Fechner and No. 5 of phosphor-bronze also by Fechner. All were heavily gilt, were of similar construction (see Fig. 1) and had nearly the same period of vibration. At Potsdam these were :—

No. 21	0·509746 seconds.
,, 5	0·508339 ,,
,, 7	0·508314 ,,

In this form of apparatus the agate knife-edge *B* (see Fig. 1) is fixed on the pendulum, and this rests in use on the corresponding agate plane carried by the pendulum stand. On top of the pendulum is securely fastened, on the one side, a small silvered glass mirror *A*, and, on the other (in reserve), a metal one. These may be adjusted by screws so that they lie accurately parallel to the vertical plane through the knife-edge.

The auxiliary adjustable pendulum is used only to determine the flexure correction for No. 21 and, for this, its period of vibration is adjusted till it is approximately equal to that of No. 21.

* This apparatus is described by Hecker in "Veröffentlichung des Kgl. Preuss. Geod. Inst., Neue Folge, No. 11."

The period of all three observing pendulums remained almost unaltered during the period between the first and last observations at Potsdam, and this may in part be ascribed to the fact that they were already thoroughly " seasoned " by their previous work. Their record goes back to the journeys undertaken by Dr. O. Hecker in 1902 and in 1904–5, for the determination of the value of gravity over the Atlantic, Pacific, and Indian Oceans. They were again used by Professor Haasemann in 1906 in carrying out the programme of the Potsdam Geodetic Institute.

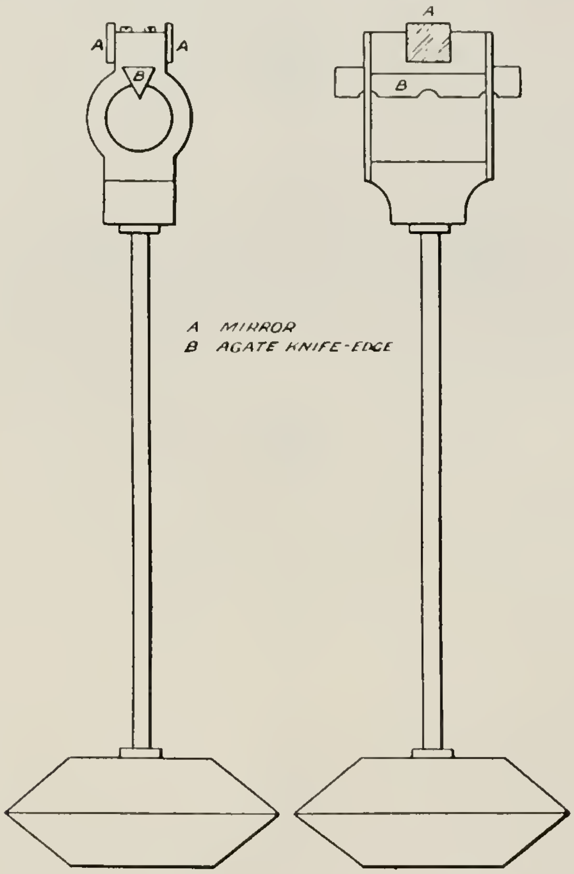

Fig. 1. Diagram showing construction of half-second pendulums.

In the series of observations here described, they acted as satisfactorily as could be expected of pendulums with such a high temperature coefficient as brass, though no doubt it would have been a very great advantage to have possessed pendulums made of invar, or even of quartz.

The chief cause for regret is that the gilding of No. 21 suffered somewhat during the course of the first winter's observations at Cape Evans. The reason for this may be the adhesion of particles of the drying agent kept within the case of the instrument in order to prevent the accumulation of hoar-frost on the mirrors. That this action has affected the period of the pendulum so little is strong evidence in support of Professor Haasemann's contention that the main factor in preserving the period unchanged is connected with the " set " of the agate knife-edge, rather than with a lack of alteration on the surface or within the mass of the pendulum.

A 2

When in use, the auxiliary pendulum is put in the place of No. 21 (position C, Fig. 2), and No. 21 is moved up to position A. It bears a mirror carried on a long arm p, so that its mirror and No. 21's mirror lie parallel to one another and in the same plane.

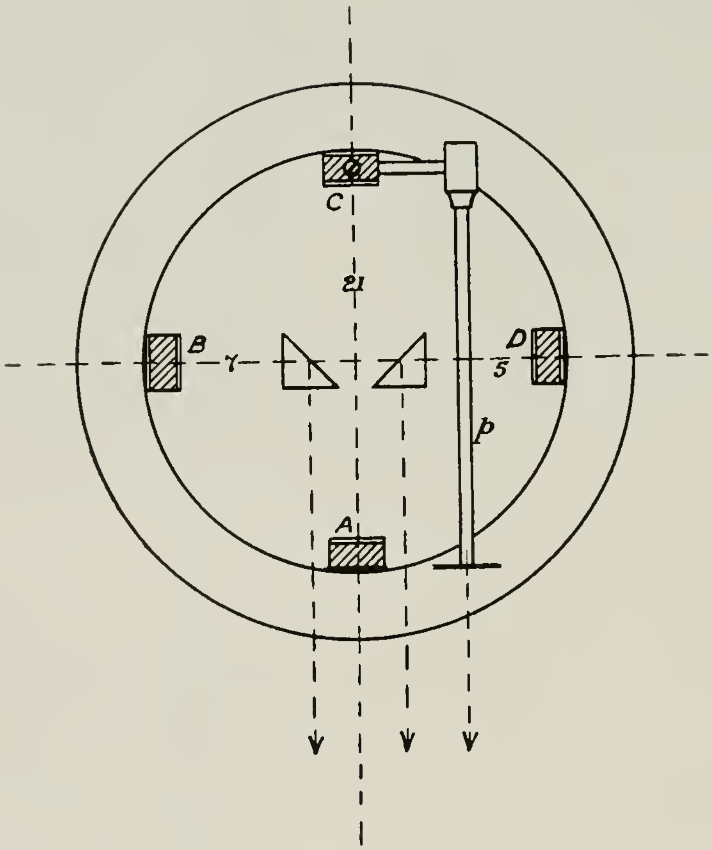

Fig. 2. Diagram showing, in plan, the relative positions of the pendulums on the stand.

The stand, which is shown from above in Fig. 2, is a heavy brass casting about 2 feet in diameter, most solidly made and supported by three heavy levelling screws with provision for clamping them in position. In order to minimise the effect of draughts, the apparatus is divided by solid vertical brass plates into four compartments, so that the pendulums swing each in its own compartment and on its own agate plane. Arrangements are provided for lowering any pendulum by means of a slow motion screw actuated from outside, until the agate knife-edge of the pendulum rests in its proper position upon the agate plane of the stand. Apparatus, with separate adjustment for regulating the amplitude, is provided for giving the pendulums the initial swing, without the necessity of lifting off the light double-walled aluminium cover. The temperature is measured by a thermometer divided to single fifths of a degree Centigrade, whose bulb projects into the bob of a dummy pendulum with hollow stem, the bob being in metallic connection with the base of instrument. Windows are provided in the cover, one for reading the thermometer and one for observing the mirrors of the three pendulums. The cover of the stand has not to be removed during the observations, thanks to the device for starting and stopping the pendulums from outside, and to the arrangement of right-angled prisms shown in Fig. 2. These have adjusting screws to enable the images from the mirrors of the three observing pendulums to be seen side by side through the same window.

The agate planes are levelled by means of auxiliary dummies with knife-edges, carrying levels in their heads.

The Clock.

Strasse and Rohde, 101.

The break-circuit clock lent by the Geodetic Institute was a second pendulum clock by Strasse and Rohde in a heavy iron case, arranged to be conveniently hung on a pillar or wall. The break-circuit arrangement consisted of a short lever arm, which was lifted by another arm carried on the pendulum, and had an attachment whereby the duration of the contact could be adjusted. This clock was used throughout the series of observations except for those at Potsdam itself, where a break-circuit clock belonging to the Geodetic Institute was used both for the initial and final comparisons.

The Coincidence Apparatus.

This apparatus was of the usual electro-magnetic type, consisting essentially of a slit in a plate carried on a lever, pivoted behind another fixed slit. Under the influence of the current through the break-circuit clock this lever is drawn down by an electro-magnet against the action of a spring and again released, in isochronism with the beat of the pendulum clock. At every "make" and at every "break" of the current, a flash of light is allowed to pass through the two slits and is observed, after reflection from the pendulum mirrors, in a telescope with cross wires, fixed above the coincidence box. When the observing pendulum is hanging freely without oscillation each flash appears in the same place with reference to the cross wires, but, when the pendulum is swinging, the flash appears to move progressively up and down as a result of the varying position of the observing pendulum when the flash passes through the two slits. Since the period of the pendulums is slightly greater than $\frac{1}{2}$ second, the pendulum falls further behind the clock at each swing. The time between two successive transits of the flash over the horizontal cross wire in the telescope is called the coincidence interval C. The pendulum thus makes $2\,C-1$ vibrations in C seconds (measured by the break-circuit clock) and the period of vibration is given by—

$$s = \frac{C}{2C-1}.$$

The amplitude of the vibration is determined by noting the reflection in the pendulum mirror of a graduated scale fixed on the front of the box. It is obtained from consideration of the distance-mirror to scale, and of the number of divisions of the scale which are seen to pass over the cross wire of the telescope.

The Thermometers.

The thermometers used were three in number :—

No. 29110, range 0° to 30° C.
,, 41203, ,, −30°+10° C.
,, 41204, ,, −30°+10° C.

They were divided in fifths of a degree Centigrade. The errors were determined at the Reichsanstalt before starting and again after return. These errors are put down in the following table :—

No. 29110.		No. 41203.		No. 41204.	
May, 1910— 0° C.—0·10	Too high	May, 1910——20° C. 0·04	Too low	May, 1910——20° C. 0·06	Too low
10° C.—0·06	,,	−10° C. 0·02	,,	−10° C. 0·02	,,
20° C.—0·06	,,	0° C. 0·02	,,	0° C. 0·00	,,
30° C.—0·16	,,	+10° C. 0·02	,,	+10° C. 0·04	,,
Nov., 1913— 0° C.—0·12	Too high	Oct., 1913——21° C. 0·02	Too high	Oct., 1913——21 C. 0·02	Too high
10° C.—0·06	,,	−11° C. 0·04	,,	−11° C. 0·04	,,
20° C.—0·08	,,	0° C. 0·04	,,	0° C. 0·06	,,
30° C.—0·16	,,	+10° C. 0·04	,,	+10° C. 0·02	,,

The change in error was assumed to be regular during the interval between the two standardizations, and the applied corrections are calculated on this assumption.

For measurement of the atmospheric pressure, the standard mercury barometer of each station was generally used, and the appropriate corrections applied.

For hygrometric measurements, recourse was had in general to wet and dry bulb thermometers, the vapour pressure of the moisture in the air being calculated from the temperatures indicated by the two.

With this particular form of apparatus, the pendulums are swung at atmospheric pressure and corrections are applied to reduce these to measurements *in vacuo*. Owing to damping by the air, the time of observation of any pendulum cannot be unduly prolonged, as otherwise the amplitude of the final oscillations becomes so small as to vitiate the accuracy of the result.

Procedure in Making Observations.

The method of procedure followed is to put down the instants of the first 10 or 20 coincidences (estimated to the nearest tenth of a second), to calculate the time of the 61st coincidence, to observe this one and the instants of the following 10 or 20 coincidences. The mean of the differences between the 1st and the 61st, the 2nd and the 62nd, and so on, gives the value of 60 coincidence intervals, from which the time of swing of the pendulum is readily deduced.* Barometer, temperature, hygrometer,

* One half of these coincidences are with ascending flash and the other half with descending flash.

and amplitude are observed before and after the observations proper, and their appropriate corrections applied in order to reduce to normal temperature and pressure. The three pendulums are swung in turn in this way. Each set of observations takes about 40 minutes and the whole series about $2\frac{1}{2}$ hours.

A specimen page from the note-books is given below.

Mean Time, 11 h. 10 m. *Date*, March 2nd, 1913, a.m. *Observer*, C. S. W.
Mean Barometer, 29·91 inches. *Pendulum Number*, 5.

	Amplitude.		Temperature.		
	Above.	Below.	Pendulum.	Dry bulb.	Wet bulb.
Beginning ...	6·2	10·3	15°·76 C.	60°·4 F.	55°·8 F.
End	3·7	7·8	·76 C.	60°·5 F.	56°·0 F.
Mean	5·0	9·0	15°·76 C.	60°·4 F.	55°·9 F.

	hr. min. sec.	hr. min. sec.		min. sec.	min. sec.
1.	2 51 0·6	3 20 24·7	Difference=	29 24·1	
2.	29·8	53·7			29 23·9
3.	59·4	21 23·4		·0	
4.	52 28·6	52·5			23·9
5.	58·2	22 22·4		·2	
6.	53 27·3	51·3			24·0
7.	57·0	23 21·2		·2	
8.	54 26·1	50·0			23·9
9.	55·9	24 20·0		·1	
10.	55 24·9	48·9			24·0
11.	54·7	25 18·8		·1	
12.	56 23·7	47·7			24·0
13.	53·5	26 17·6		·1	
14.	57 22·6	46·5			23·9
15.	52·3	27 16·5		·2	
16.	58 21·3	44·4			24·1
17.	51·0	28 15·4		·4	
18.	59 20·1	44·3			24·2
19.	49·9	29 14·1		·2	
20.	3 0 18·9	43·2			24·1
			Means	29 24·16	29 24·0
			Δ 60=	29 24·08	

It is clear that the observation of "time of swing" of the pendulums in any location does not give a value for gravity. Only when the length l of the pendulum is invariable (the distance between centre of gravity and centre of suspension), is one able to compare the value of gravity at two spots from the observed times of swing. The formula is—

$$S = 2\pi \sqrt{\frac{l}{g}},$$

$$S_0 = 2\pi \sqrt{\frac{l}{g_0}},$$

or

$$g/g_0 = \left(\frac{S_0}{S}\right)^2,$$

or

$$g = \frac{g_0 S_0^2}{S^2}$$

(S_0, g_0 = time of swing and value of gravity at Potsdam = 981·292).

In these observations, Potsdam was taken as the base station and the values of gravity "g" at other places calculated from the relation above.

Corrections to be applied to the observed time of swing, S.

(1) *For amplitude of swing.*—The formula for reduction of S to the time of swing of an infinitely small arc S′ is

$$S' = S\left\{1+(\tfrac{1}{2})^2 \sin^2\frac{A}{2} + \left(\frac{1\times 3}{2\times 4}\right)^2 \sin^4\frac{A}{2} + \ldots\right\},$$

where A=mean amplitude of vibration at the beginning and end of the observation.

If the amplitude is only about 20 minutes of arc, the first two terms give a sufficiently close approximation, and this reduces to

$$\Delta a = S - S' = -\frac{S}{4}\sin^2\frac{A}{2} = -S\frac{A^2}{16}.$$

(2) *Correction for temperature.*—The reduction of S to the temperature of 0° C. is expressed as an empirical relation which is found to be of the linear form, i.e. $\Delta t = -kt$ (t=mean value of the pendulum temperature in degrees Centigrade).

For the determination of k, special observations are made at Potsdam for the time of swing of the pendulums under widely varying conditions of temperature, and this requires the use of a special external case in which the temperature may be artificially raised. The results* are given below :—

No. 21, $k=(48\cdot 74 \pm 0\cdot 05)\ 10^{-7}$.
,, 5, $k=(45\cdot 30 \pm 0\cdot 03)\ 10^{-7}$.
,, 7, $k=(49\cdot 07 \pm 0\cdot 13)\ 10^{-7}$.

* Hecker, "Bestimmung der Schwerkraft auf dem Indischen und Groszen Ozean," 1908.

(3) *Correction for barometer.*—The reduction to a vacuum, or correction for density of the air, is calculated from the formula

$$\Delta d = -k'D, \text{ where } D = \frac{B - \frac{3}{8}E}{760\,(1 + 0\cdot00367t)}.$$

Here D = density of air,

B = barometer in millimetres,

t = temperature in degrees Centigrade,

E = water vapour pressure corresponding to the observed reading of the hygrometer, or wet and dry bulb thermometers,

the values of k' below were determined at Potsdam by the use of a special vacuum chamber, in which the whole instrument was put in order to determine the value of S under varying conditions of pressure.

$$\text{No. } 5,\ k' = (641 \pm 11) \times 10^{-7},$$
$$\text{,, } 7,\ k' = (640 \pm 3\cdot3) \times 10^{-7},$$
$$\text{,, } 21,\ k' = (650 \pm 6\cdot0) \times 10^{-7},$$

the mean is taken as 664×10^{-7} and, in reducing the results, the same coefficient for density correction is applied to all pendulums.

(4) *Correction for clock rate.*—Since there are 86,400 secs. in the day and the mean time of swing of the pendulums is 0·509 sec., the correction for a rate of 1 sec. a day is

$$\frac{0\cdot509}{86{,}400} = 58\cdot9 \times 10^{-7}.$$

The correction is additive to the observed time of swing when the clock has a losing rate, and vice versa.

Generally, the correction for rate is $\frac{0\cdot509}{86{,}400} \times \Delta$; where Δ=rate in secs. per day.

(5) *Flexure correction.*—This correction, which is necessary to reduce the time of swing to that which would occur on a perfectly rigid pillar and stand, is the one which is the most troublesome to evaluate. The method used is that due to Professor Schumann, wherein the flexure, or *mitschwingen*, correction is calculated from the mutual action of two pendulums of equal period swinging in the same plane.

The method of observation is as follows :—Two pendulums (say, Nos. 5 and 7) of approximately the same period are put on their respective agate planes. Of these, one—the " driven " pendulum—is brought to rest, while the other—the " driving " pendulum—is set swinging at a given instant. From the ratio of the amplitudes of vibration of the two pendulums (measured by the ratio of the scale readings), and the interval since the " driving " pendulum was started, the flexure correction is readily calculated. The result of the motion of the pillar is such as to increase the virtual length of the pendulums by a small amount, which gives rise to a small change in the period of vibration Δs.

From theoretical considerations, the following formula has been calculated, which holds good after the pendulums have been swinging a few minutes (say, 10–15 minutes) :—

$$\Delta s = \frac{a}{A} \frac{T^2}{\pi (t-t_0)} \times \frac{m_2 h_2}{m_1 h_1}.$$

m_2 = mass of driven pendulum.
m_1 = mass of driving pendulum.
T = 0·508=mean time of swing of the two pendulums.
$t - t_0$=time in seconds since the release of the driving pendulum.
a = amplitude of driven pendulum at time t.
A = amplitude of driving pendulum at time t.
h_1 and h_2=the distances between centre of suspension and centre of gravity of the pendulums.

The driving pendulum is set swinging at the time t_0, which is usually an even half-minute. After about 10 minutes, when the driven pendulum has received a measurable amplitude of vibration, the procedure runs :—

1. At an even minute, —observation, through the telescope, of the scale reading above and below for driving pendulum.
2. 20 secs. later, – observation of the scale readings for driven pendulum.
3. 20 secs. later still, —(2) repeated.
4. 20 secs. later (at the full minute), —(1) repeated.

The mean of 1 and 4 gives a measure of " A," and the mean of 2 and 3 gives a measure of " a " at the mean time t, which is an even half-minute, so that the value of $t - t_0$ is given in even minutes.

A full minute is now allowed to elapse and the observation repeated at the end of this period. In general, six independent series were observed. The value of Δs is calculated from each and the mean taken as the correction to be applied to the observed time of vibration.

The value of Δs is, in general, different in the two directions at right angles to one another. For determining the value in the plane at right angles to the axis of the observing telescope, Nos. 5 and 7 are used on their respective agate planes. In order to determine the correction to be applied to No. 21, which swings in a plane parallel to the line of sight, use is made of the auxiliary pendulum. This has an attachment for varying the period of vibration so that it may be adjusted to isochronism with No. 21. For making this observation, No. 21 is brought forward to the agate plane A

(Fig. 2) in front of the stand, and laid in the place of the dummy pendulum with thermometer. The auxiliary is put in the place of No. 21, and a long arm is firmly attached to its head, carrying a mirror at the end, which lies alongside the mirror of No. 21. The mirror of the auxiliary may be readily adjusted so that the reflections of the scale from the two mirrors appear side by side in the telescope.

A specimen form in which the observations for flexure are made is put down below.

Apr. 3rd, 1913, 2.30 p.m. Nos. 21 and Auxiliary.

" Driving " pendulum = auxiliary.

" Driven " ,, = No. 21.

Start 7 hr. 35½ min.		
Time.	Amplitude.	
hr. min.		
7 51	16·1	
51½	0·6*	log Δs=6·5059
52	16·0	
53	15·8	
53½	0·7	6·5271
54	15·7	
55	15·6	
55½	0·8	6·5477
56	15·4	
57	15·2	
57½	0·85	$\bar{6}$·5439
58	15·0	
59	14·8	
59½	0·9	$\bar{6}$·5426
8 00	14·6	
1	14·3	
1½	0·95	$\bar{6}$·5434
2	14·3	
3	14·1	
3½	1·0	$\bar{6}$·5427 ; flexure correction
4	14·0	$\Delta s = 34·7 \times 10^{-7}$ sec.

* The values here given are the means of the values observed 10 seconds before and after the half-minute.

The magnitude of the flexure correction depends largely on the rigidity of the pendulum stand, but also upon the rigidity of the pillar on which the stand is placed. It depends on the tightness of clamping of the levelling screws and also on the position of the screws themselves. The smaller the distance between the points of the levelling screws and the base of the instrument, the less is the correction for flexure.

The extreme values noted during these determinations were 16 and 94 units in the 7th decimal place. The smallest of these was measured when the pendulums were swung at Winter Quarters in a small cave dug into the ice. Here, the temperature of the air was very low (from $-20°$ to $-30°$ C.) and the apparatus was set up on a solid block or shelf of ice left unsupported only along one side. The highest value for Δs was measured at Christchurch.

The magnitude of this variation (from 16 to 94) might lead one to enquire with what accuracy the calculated value represents the true correction. (The probable error of the determination gives the calculated value from a single series as about $\pm 0 \cdot 6$ in the 7th decimal place, but, since the formula used is at best an approximation, it is proper to investigate the point raised above.)

An experimental investigation by Professor Haasemann* answers our query at once. By measuring the actual horizontal movement corresponding to the application of a known force at the point of suspension of the pendulums, he has made independent observations of the flexure correction, and has found that, in the mean, the value obtained by the latter method is greater than that obtained by the use of two pendulums of equal period, by a quantity $0 \cdot 7 \times 10^{-7}$, and this is not far from the probable error of the observation itself.

The stations at which pendulums have been swung are, in order of observation—Potsdam, 1910, Christchurch, 1910 (N.Z.), Winter Quarters (Ross Island—Series A and B in 1911, series C and D in 1912), Christchurch, 1913, Wellington, 1913, Melbourne, 1913, Potsdam, 1913.

The observations at Christchurch were undertaken in order to have a comparison with similar observations made by L. Bernacchi of the "Discovery" Expedition. The Melbourne observations were made with the object of having a secondary comparison at a spot whose value of gravity was well known. This was necessary in case the period of our pendulums became changed on the long journey back to Potsdam. The Wellington observations were undertaken at the request of Professor Laby, who pointed out that there was no accurate determination of the value of gravity in New Zealand.

The details of the observations and the discussion of the results will now be put down in detail, in the order—Potsdam I and II, Christchurch, 1910, Winter Quarters, Christchurch, 1913, Wellington, Melbourne.

* "Bestimmung der Intensität der Schwerkraft von Hanover," Berlin, 1909, p. 154.

POTSDAM I.

Observations by Professor Haasemann in May, 1910, in East Cellar.

Latitude, 52° 22′·9 N. *Longitude*. 13°·03′·9 E.
Height above sea-level, 83 *metres*.

Clock rate.—For the initial observations at Potsdam, one of the Observatory clocks (Riefler 96) was used in comparing the time of swing of the pendulums. The rates of this clock were determined in the usual way by comparison with the standard clock of the Observatory, and were given as—

May 18th and 19th	.. ..	—0°·05 daily.
,, 19th ,, 20th	.. ..	—0°·02 ,,
,, 20th ,, 21st	.. ..	—0°·02 ,,
,, 23rd ..	.. .. ..	—0°·05 ,,
,, 24th ..	.. .. ..	—0°·02 ,,

The probable error may be taken as less than ±0·01 sec. daily.

Temperature.—The temperature, given by a thermometer divided in fifths, was read by an auxiliary telescope and estimated to hundredths of a degree. The corrections to be applied to the thermometer are given below:—

P.T.R. 15955 at 0° C., correction	.. .. ..	—0°·04 C.
10° C., ,,	.. .. ..	—0°·04 C.
20° C., ,,	.. .. ..	—0°·04 C.
30° C., ,,	.. .. ..	—0°·04 C.
40° C., ,,	.. .. ..	—0°·04 C.

The total range of temperature during the series of observations was from 13°·22 C. to 13°·74 C., a variation of 0°·52 C.

Barometer.—For a calculation of the barometric reductions, the readings of aneroid barometer Bohne 937 were taken and the correction —5·6 mm. applied. The total range during the observations was from 752 to 758 mm.

Hygrometer.—A Koppe's hair hygrometer was used in this series.

Flexure.—Observations for flexure were made as under:—

May 16th	.. .. ..	Nos. 5 and 7, 42 10^{-7};	No. 21, 52 10^{-7}.
,, 16th	.. .. ..	,, ,, 44;	,, 49.
,, 28th	.. .. ..	,, ,, 44;	,, 51.

The corrections applied are 43×10^{-7} sec. for 5 and 7, and 51×10^{-7} sec. for No. 21.

The analysis of Professor Haasemann's results is given in Table I.

In Table II, the results are grouped so as to show the variations of the individual pendulums.

TABLE II.

	Time of Swing.							
	Pendulum No. 5.		Pendulum No. 7.		Pendulum No. 21.		Mp=Mean of the pendulums.	
	A.	B.	A.	B.	A.	B.	A.	B.
1.	0·5083397 sec.		0·5083135 sec.		0·5097451 sec.		0·5087994 sec.	
		393		134		455		994
2.	389		133		458		993	
3.	394		131		459		995	
		392		133		461		995
4.	384		134		463		995	
5.	393		141		463		999	
		392		145		462		8000
6.	390		149		461		8000	
7.	391		142		466		8000	
		396		135		462		998
8.	400		128		457		995	
9.	382		131		462		992	
		389		131		460		993
10.	396		130		458		995	
Mean .	. No. 5. 0·5083392		No. 7. 0·5083136		No. 21. 0·5097460		General mean of all pendulums—0·5087996	

Differences from general mean :—

$M_p - 5$, 4604×10^{-7} sec. $M_p - 7$, 4860×10^{-7} sec. $21 - M_p$, 9464×10^{-7} sec.

In the above Table, Column B represents the mean of a pair of day and night observations.

Accuracy of the Results.

By the use of Column A, Table III is formed. Here v represents the difference from the mean value for each pendulum, and (vv) the square of this difference.

Table III.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	5×10^{-7} sec.	25	1×10^{-7} sec.	1	9×10^{-7} sec.	81	2×10^{-7} sec.	4
	3	9	3	9	2	4	3	9
	2	4	5	25	1	1	1	1
	8	64	2	4	3	9	1	1
	1	1	5	25	3	9	3	9
	2	4	13	169	1	1	4	16
	1	1	6	36	6	36	4	16
	8	64	8	64	3	9	1	1
	10	100	5	25	2	4	4	16
	4	16	6	36	2	4	1	1
$\Sigma(vv)$ ...		288		394		158		74

From these values, the probable errors of the observed times of swing of the different pendulums are calculated in the usual way.

Probable error of a single observation $e_x = 0\cdot6745\sqrt{\frac{\Sigma(vv)}{n-1}}$, where n = number of observations.

$$\left.\begin{array}{llll}
\text{Probable error of a single observation by No. 5} & e_5 & = 3\cdot7\times10^{-7} \text{ secs.} \\
\quad\text{,,} \quad\text{,,} \quad\text{,,} \quad\text{,,} \quad 7 & e_7 & = 4\cdot4 \\
\quad\text{,,} \quad\text{,,} \quad\text{,,} \quad\text{,,} \quad 21 & e_{21} & = 2\cdot7 \\
\quad\text{,,} \quad\text{,,} \quad\text{,, mean pendulum} & e_m & = 1\cdot9\times10^{-7} \text{ secs.}
\end{array}\right\} \quad . \; . \quad (1)$$

Probable error of the mean result for any pendulum,

$$p_x = 0\cdot6745\sqrt{\frac{\Sigma(vv)}{n(n-1)}}.$$

$$\left.\begin{array}{l}
\text{Therefore, the probable error of mean result given by No. } 5 = p_5 = 1\cdot2\times10^{-7} \text{ secs.} \\
\quad\text{,,} \quad\text{,,} \quad\text{,,} \quad\text{,,} \quad\text{,,} \quad 7 = p_7 = 1\cdot5 \\
\quad\text{,,} \quad\text{,,} \quad\text{,,} \quad\text{,,} \quad\text{,,} \quad 21 = p_{21} = 0\cdot9 \\
\quad\text{,,} \quad\text{,} \quad\text{,,} \quad\text{,, mean pendulum} = p_m = 0\cdot6\times10^{-7} \text{ secs.}
\end{array}\right\} (2)$$

Considering paired observations alone (column B), we get—

Table IV.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	1×10^{-7} sec.	1	-2×10^{-7} sec.	4	-5×10^{-7} sec.	25	-2×10^{-7} sec.	4
	0	0	-3	9	1	1	1	1
	0	0	9	81	2	4	4	16
	4	16	1	1	2	4	2	4
	-3	9	-5	25	0	0	-3	9
$\Sigma(vv)$ ...	=	26		120		34		34

The probable error of a single pair of observations (morning and evening) is, therefore—

$$e'_x = 0 \cdot 6745 \sqrt{\frac{\Sigma (vv)}{4}}.$$

$$\left.\begin{array}{lll} \text{For No. } 5 = e'_5 = 1 \cdot 7 \times 10^{-7} \text{ sec., compared with } & e_5 = 3 \cdot 7 \times 10^{-7} \text{ sec.} \\ \text{,, ,, } 7 = e'_7 = 3 \cdot 7 \qquad \text{,, ,,} & e_7 = 4 \cdot 4 \\ \text{,, ,, } 21 = e'_{21} = 2 \cdot 0 \qquad \text{,, ,,} & e_{21} = 2 \cdot 7 \\ \text{the mean pendulum} = e'_m = 2 \cdot 0 \qquad \text{,, ,,} & e_m = 1 \cdot 9 \end{array}\right\} \quad . \quad (3)$$

The probable error of the mean of all pairs of observations is put down below and, for comparison, the numbers referring to the mean of single observations.

$$\left.\begin{array}{ll} p'_5 = 0 \cdot 8 \times 10^{-7} \text{ sec.} & p_5 = 1 \cdot 2 \times 10^{-7} \text{ sec.} \\ p'_7 = 1 \cdot 7 \quad \text{,,} & p_7 = 1 \cdot 5 \quad \text{,,} \\ p'_{21} = 0 \cdot 9 \quad \text{,,} & p_{21} = 0 \cdot 9 \quad \text{,,} \\ p'_m = 0 \cdot 9 \quad \text{,,} & p_m = 0 \cdot 6 \quad \text{,,} \end{array}\right\} \quad . \quad . \quad . \quad (4)$$

A useful test for the occurrence of systematic errors is furnished by a comparison of the values of e'_x and e_x. From (3), we may take the mean of the values of e_5, e_7 and e_{21}—(a), and compared them with the mean of the values e'_5, e'_7 and e'_{21}—(b). Since the latter give the probable errors of a pair of observations, we should find that the ratio of (b) to (a) should be roughly that of 1 to $\sqrt{2}$, provided always that no systematic error has been introduced.

From (3), we find that the mean of $e'_x = 2 \cdot 5 \times 10^{-7}$ sec.

,, ,, ,, $e_x = 3 \cdot 6 \times 10^{-7}$ sec.

The ratio e'_x/e_x is therefore $1/1 \cdot 44$ instead of the expected value $1/1 \cdot 414$. It seems probable, therefore, that the rate of the clock was very even, and that no systematic differences in clock rate were initiated between the morning and the evening observations.

Perhaps an easier test is that of simple inspection from Table V, where the a.m. and p.m. observations are put down in separate Columns.

TABLE V.—Time of swing of mean pendulum.

	a.m.	p.m.
	0·5087993 sec.	0·5087994 sec.
	7995 ,,	7995 ,,
	8000 ,,	7999 ,,
	7995 ,,	8000 ,,
	7995 ,,	7992 ,,
Mean	0·5087994 ,,	0·5087996 ,,

We may therefore say that, in this series (Potsdam I), there were probably no systematic differences in the working of the clock or in the method of comparing the clock times with the time of vibration of the pendulum—that is, the coincidence apparatus was also working well. The importance of this last point can be readily estimated when one considers the effect of a small retardation in the time elapsing between the "break" of the clock circuit, and the movement of the lever in the coincidence apparatus. Variations in the action of the attracting electromagnets, due to running down of the battery, rise of temperature in the coils, together with change in the permeability of the iron core, may all produce apparent fluctuations of considerable magnitude in the clock rate.

Thus, during the course of the observation on a single pendulum, if the action of the lever has become retarded by 0·005 sec. during the 30 mins. interval between the initial and final series of readings, the apparent daily rate will differ from the true one by 0·24 sec., and this requires a correction to the time of swing of 14 units in the 7th decimal place.

The observations at Potsdam show that the effect of all these factors is negligible under such favourable conditions. There are, however, theoretical objections to this form of coincidence apparatus, and the fact that serious discrepancies in the observations made at Cape Evans pointed to a defect in the coincidence apparatus, led to the evolution of a form in which no moving parts are involved. This arrangement will be found described under the discussion of the observations at Christchurch, 1913.

It must be pointed out that the foregoing calculations of the probable errors are in no case a measure of the actual "errors of observation." To get an estimate of the merit of the comparison between pendulum and clock, it is, of course, necessary that all the variables—rate, temperature, barometer, etc.—should remain constant throughout the series of observations. In practice, of course, this never occurs, but one is able by a suitable handling of the observations to obtain a value which is a fair measure of the probable error of the comparison between clock and pendulums. This is most simply done by forming the differences between the time of swing of the mean pendulum and Nos. 5, 7 and 21. These differences will be almost independent of clock rate and such other variables, and the estimation of the probable error of such a difference will be some measure of the observational accuracy alone.

In Table VI below these differences are put down, and the probable error of a single difference evaluated in the usual manner by the help of Table VII.

TABLE VI.

	M_p-5.	M_p-7.	$21-M_p$.
	4597×10^{-7} sec.	4859×10^{-7} sec.	9457×10^{-7} sec.
	4604	60	65
	4601	64	64
	4611	61	68
	4606	58	64
	4610	51	61
	4609	58	66
	4595	67	62
	4610	61	70
	4599	65	63
Mean	4604×10^{-7} sec.	4860×10^{-7} sec.	9464×10^{-7} sec.

TABLE VII.

	M—5.		M—7.		21—M.	
$v(vv)$ ...	7×10^{-7} sec.	49	1×10^{-7} sec.	1	7×10^{-7} sec.	49
	0	0	0	0	1	1
	3	9	4	16	0	0
	7	49	1	1	4	16
	2	4	2	4	0	0
	6	36	9	81	3	9
	5	25	2	4	2	4
	9	81	7	49	2	4
	6	36	1	1	6	36
	5	25	5	25	1	1
(vv) ...		314		182		120

Probable error of one difference, $M_p-5 = 3\cdot9\times10^{-7}$ sec.

" " " $M_p-7 = 3\cdot0$ "

" " " $21-M_p = 2\cdot4$ "

Mean $3\cdot1\times10^{-7}$ sec.

This value is only slightly less than the mean of e_5, e_7 and e_{21}, showing that the observations were comparatively free from errors introduced by irregular clock rate.

POTSDAM II.

At the conclusion of the whole programme of work in October, 1913, the pendulums were again swung in Potsdam. On this occasion, they were observed in the middle cellar on a "*Feldpfeiler*" fixed with plaster of Paris to the solid cement floor of the cellar.

Time.—The break circuit clock used throughout this series was the same one as used in the first series. The rate was determined in the ordinary way by Professor Wanach and, after correction for barometer, this may be taken as :—

TABLE VIII.

	Sec.
Oct. 4—3·0—5·5 p.m.	—0°·14 sec. daily.
,, 5—9·0 A—11·5 a.m.	—0°·13 ,,
,, 5—5·0 P—7·0 p.m.	—0°·14 ,,
,, 6—9·0 A—11·5 a.m.	—0°·15 ,,
,, 6—4·0 P—7·0 p.m.	—0°·15 ,,
,, 7—9·0 A—7·0 p.m....	—0°·16 ,,
,, 7—4·0 P—7·0 p.m....	—0°·17 ,,
,, 8—8·5 *a*—11·0 a.m.	—0°·18 ,,

Temperature.—The temperature was given by thermometer 29110, reading to one-fifth of a degree Centigrade, and was estimated by telescope to hundredths of a degree. The errors were redetermined by the Physikalische Technische Reichsanstalt and found to be as follows :—

at 0° C.	0·12 C.	too high.
,, 10° C.	0·06 C.	
,, 20° C.	0·08 C.	
,, 30° C.	0·16 C.	

The total range of temperature during the observations was from 14°·47 C. to 14°·74 C.—a difference of only 0°·27 C.

The greatest temperature change during the course of observations on any single pendulum was 0·03° C., corresponding to a rate of change of 0°·05 per hour. In this series, the dummy pendulum rested, not on the brass block provided with the apparatus, but on a cork disc of the same size—a procedure which had been followed in all observations subsequent to those of July, 1911.

Barometer.—The barometric pressure was read by Aneroid Bohne 937, and a correction applied to reduce to the true barometric height. The total range of pressure was from 747·9 to 754·1 mm. Percentage humidity was measured by a Koppe's hygrometer.

Flexure.—Observations for flexure correction were made as under :—

	Nos. 5 and 7.	No. 21.
Oct. 6th, p.m.	$38 \cdot 3 \times 10^{-7}$ sec.	—
„ 7th, a.m.	$38 \cdot 6$ „	$48 \cdot 0 \times 10^{-7}$ sec.
„ 7th, p.m.	—	$48 \cdot 2$ „
Mean	$38 \cdot 45 \times 10^{-7}$ sec.	$48 \cdot 10 \times 10^{-7}$ sec.

The results of the observations are put down in Table IX.

To form an estimate of the accuracy of results, the values of the individual pendulums are subtracted from the mean and put down in Table X, Column A.

TABLE X.—Times of Swing.

	No. 5.		No. 7.		No. 21.		Mean pendulum.	
	A.	B.	A.	B.	A.	B.	A.	B.
1.	0·5083372 sec.		0·5083140 sec.		0·5097439 sec.		0·5087984 sec.	
		371		140		439		984
2.	370		139		439		983	
3.	385		134		444		988	
		385		136		445		989
4.	385		138		446		990	
5.	392		140		451		994	
		392		139		454		994
6.	391		138		457		995	
7.	382		135		443		987	
		380		135		441		986
8.	378		135		439		984	
Mean	0·5083382 sec.		0·5083137 sec.		0·5097445 sec.		0·5087988 sec.	
Differences from the mean pendulum	4606×10^{-7} sec.		4851×10^{-7} sec.		9457×10^{-7} sec.			

TABLE XI.

	No. 5.		No. 7.		No. 21.		Mean.	
$v\ (vv)$ ...	10	100	3	9	6	36	4	16
	12	144	2	4	6	36	5	25
	3	9	3	9	1	1	0	0
	3	9	1	1	1	1	2	4
	10	100	3	9	6	36	6	36
	9	81	1	1	12	144	7	49
	0	0	2	4	2	4	1	1
	4	16	2	4	6	36	4	16
$\Sigma\ (vv)$ ...		459		41		294		147

From Table XI, the probable errors of a single observation by the different pendulums are calculated as before.

We find, thus, $e_5 = 5 \cdot 4 \times 10^{-7}$ sec.

$$e_7 = 1 \cdot 6$$
$$e_{21} = 4 \cdot 3$$
$$em = 3 \cdot 0 \times 10^{-7} \text{ sec.}$$

The probable error of the mean result by the different pendulums is also calculated, and the values come out as follows :—

$$p_5 = 1 \cdot 9 \times 10^{-7} \text{ sec.}$$
$$p_7 = 0 \cdot 6$$
$$p_{21} = 1 \cdot 5$$
$$p_m = 1 \cdot 0 \times 10^{-7} \text{ sec.}$$

In this series, simple inspection is sufficient to show us that a systematic error of some kind was present. It will be noted that the observations run very closely in pairs. Thus, evening observations agree well with the following morning observations, while there is disagreement between a.m. observations and the succeeding p.m. observations on the same day.

To show this discrepancy better we will form the following Table :—

Table XII.—Time of Swing.

No. 5.		No. 7.		No. 21.		Mean.	
p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.
0·5083372 sec.	370	0·5083140 sec.	139	0·5097439 sec.	439	0·5087984 sec.	983
385 ,,	385	134 ,,	138	444 ,,	446	988 ,,	990
392 ,,	391	140 ,,	138	451 ,,	457	994 ,,	995
382 ,,	378	135 ,,	135	443 ,,	439	987 ,,	984
p.m.	a.m.	p.m.	a.m.	p.m.	a.m.	p.m.	a.m.
Mean 0·5083383 sec.	381	0·5083137 sec.	137	0·5097444 sec.	445	0·5087988 sec.	988

The only explanation possible for the sudden changes from a.m. observation to the following p.m. observation is that changes have occurred which have not been allowed for. These changes, moreover, must have occurred between the two times of observation, or at about noon on each day. Temperature and barometer changes we can at once neglect as insufficient to cause these differences, but there remain variations due to changes in clock rate and to changes in the apparatus itself, such as change of level and of rigidity. It will be noticed that pendulums No. 5 and 21 seem to show the errors most, while No. 7 appears to have remained little changed throughout. This might argue a possible change in the position of the levelling screw nearest to pendulums

5 and 21. At the end of the series, however, the instrument was still in very good adjustment as to level, and the clamping screws remained tightly fixed throughout. The other possibility is that of varying clock rate. It is, however, difficult to see why sudden changes should occur in the clock rate between 11 a.m. and 4 p.m. The only possible light that can be thrown on the subject is the fact that the comparison of the clock was made at noon each day. It should, however, be pointed out that the probable error deduced from the preceding results is by no means large, and that the reason for suspicion of the possibility of a systematic error lies in the very close agreement between the p.m. observations and the succeeding a.m. ones.

Expressed in other terms, it means that the probable error of a single observation deduced from any such pair as mentioned is less than the probable error deduced from all eight observations, and that the probable error of such a pair is no less than that of a single observation.

This is brought out by the figures in Table XIII, by calculation of the probable errors of pairs of observations e_x'.

Table XIII.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	11×10^{-7} sec.	121	3×10^{-7} sec.	9	6×10^{-7} sec.	36	4×10^{-7} sec.	16
	3	9	1	1	0	0	1	1
	10	100	2	4	9	81	6	36
	2	4	2	4	4	16	2	4
Σ (vv) ...		234		18		133		57

A comparison of the values of e'_x and e_x is put down for greater clearness in Table XIV, and it will be seen from this how closely the two values approach one another.

Table XIV.

Probable error of a pair of observations.	Probable error of a single observation.
$e'_5 = 5\cdot9\times10^{-7}$ sec.	$e_5 = 5\cdot4\times10^{-7}$ sec.
$e'_7 = 1\cdot6$	$e_7 = 1\cdot6$
$e'_{21} = 4\cdot4$	$e_{21} = 4\cdot3$
$e'_m = 2\cdot9$	$e_m = 3\cdot0$

Tables XV and XVI have also been formed in order to show the differences for each pendulum from the mean pendulum, and to calculate from these our measure of the accuracy of comparison between clock and pendulums.

TABLE XV.

M_p-5.	M_p-7.	$21-M_p$.
4612×10^{-7} sec.	4844×10^{-7} sec.	9455×10^{-7} sec.
13	44	56
03	54	56
05	52	56
02	54	57
04	57	62
05	52	56
06	49	55
Mean 4606	4851	9457

TABLE XVI.

	M_p-5.		M_p-7.		$21-M_p$.	
v (vv)	6×10^{-7} sec.	36	7×10^{-7} sec.	49	2×10^{-7} sec.	4
	7	49	7	49	1	1
	3	9	3	9	1	1
	1	1	1	1	1	1
	4	16	3	9	0	0
	2	4	6	36	5	25
	1	1	1	1	1	1
	0	0	2	4	2	4
$\Sigma(vv)$		116		158		37

Probable error of one difference—

$$\begin{aligned} M_p-5 &= 2\cdot7\times10^{-7} \text{ sec.} \\ M_p-7 &= 3\cdot2 \\ 21-M_p &= 1\cdot5 \\ \text{Mean} \quad & \quad 2\cdot5\times10^{-7} \text{ sec.} \end{aligned}$$

By comparison with the corresponding values obtained in the first Potsdam observations, we see that the second series of observations appear to have a slight advantage. Thus, notwithstanding the fact that, by comparison of the values of e_m alone in the two cases, the accuracy of the result is seen to be much greater in the initial observations.

CHRISTCHURCH, 1910.

Latitude = 43° 31′ 50″ S. *Longitude* = 172° 38′ 9″ E.

OBSERVATIONS ON EAST PILLAR OF ABSOLUTE MAGNETIC HUT (BUILT ENTIRELY OF WOOD).

Height above sea-level, 25 feet.

Clock rate.—The clock rate of the sidereal clock lent to the Expedition, and hereafter denoted as "S.C.," was determined by observation of stars at meridian passage by means of the small portable transit instrument, set up on a concrete pillar erected in the Observatory grounds by the kindness of Mr. Skey. The fixed mark was furnished by a small light on a wooden post well planted in the ground towards the south. The clock was hung on the wall of the absolute hut some 40 yds. away from the instrument. In order to hear the beat of the clock, the coincidence apparatus was brought out close to the transit instrument with a long lead of flexible wire at the commencement, and replaced under cover at the close, of each set of time observations. The disadvantage of this arrangement was, of course, that no method was provided for determining to which seconds and to which minute the beats referred. To settle this point, another observer, as the star became due, would betake himself to the clock, note the minute and start to walk slowly towards the transit instrument, meanwhile counting the seconds aloud. As soon as he was clear of the building, the coincidence ticks became audible, and in this way the correct time of passage was estimated to one-tenth of a second by ear and eye in the usual manner.

The observed rates were very discordant and gave in the mean—

November 17th–18th	.. ..	0·30 sec.	gaining,	± 0·04	from	3 stars.
,, 18th–19th	.. ..	1·03 ,,	,,	± 0·32	,,	,,

The reason for the discordance of these results may be put down largely to the limitations of the transit instrument. It was loose in every joint and the collimation constant changed at every touch of the hand. For this reason, and for the additional one that the clock and the pendulum apparatus in the small wooden hut were subject to huge variations in temperature, very little reliance can be placed on the results.

The temperatures recorded by the thermometer in the pendulum case during the observation on November 18th, 1910, varied from 13°·31 C. in the morning to 26°·38 C. in the afternoon—a range of 13° between 9 a.m. and 5 p.m.

Flexure.—The observations for flexure were made on three occasions and gave the following values :—

	Nos. 5 and 7.	No. 21.
	$69·4 \times 10^{-7}$ sec.	$92·1 \times 10^{-7}$ sec.
	69·7	98·0
	72·3	91·7
Mean	$70·5 \times 10^{-7}$ sec	$93·9 \times 10^{-7}$ sec.

Temperature.—The temperature was measured by thermometer No. 29110 in the dummy pendulum resting on its metal base, and the appropriate corrections applied. The temperature gradient from floor to roof was not measured.

Barometer.—Barometer Hicks No. C 895 was read three times during each swing by each pendulum, and the hygrometric correction was calculated from the readings of the standard wet and dry bulb thermometers of the Observatory.

The rate of the sidereal clock "S.C." was obtained directly from the time observations, and there is strong internal evidence that the rate did not remain constant during any period of 24 hours. This anomalous behaviour may have been caused by a new suspension strip for the pendulum, which was made by a local jeweller to replace that broken on the journey from Potsdam.

The results of the observations are given in Table XVII.

The final figures, it will be seen, are very discordant. Even after application of the correction for temperature lag in Table XVIII, there is little improvement. The differences from the mean of each pendulum are also given in this Table and the squares of these differences.

TABLE XVIII.

	No. 5.	No. 7.	No. 21.	Mean.
	0·5085170 sec.	0·5085170 sec.	0·5099471 sec.	0·5090037 sec.
	315 ,,	058 ,,	359 ,,	0·5089911 ,,
	408 ,,	143 ,,	442 ,,	998 ,,
	393 ,,	112 ,,	443 ,,	983 ,,
Mean	0·5085396	0·5085121	0·5099129	0·5089982

	v.	$(vv.)$	v.	$(vv.)$	v.	$(vv.)$	v.	$(vv.)$
	$+74\times10^{-7}$ sec.	5476	$+49\times10^{-7}$ sec.	2401	$+42\times10^{-7}$ sec.	1764	$+45\times10^{-7}$ sec.	2025
	-81	6561	-63	3969	-70	4900	-71	5041
	$+12$	144	$+22$	484	$+13$	169	$+16$	256
	-3	9	-9	81	$+14$	196	$+1$	1
$\Sigma(vv)$		12190		6935		7029		7323

From this, we get the probable errors of a single result:—

$$e_5 = 43\cdot0\times10^{-7} \text{ sec.}$$
$$e_7 = 32\cdot4 \quad ,,$$
$$e_{21} = 32\cdot7 \quad ,,$$
$$e_m = 33\cdot3\times10^{-7} \text{ sec.}$$

The probable errors of the mean result are :—

$$\begin{aligned} p_5 &= 21\cdot5\times10^{-7} \text{ sec.} \\ p_7 &= 16\cdot2 \quad ,, \\ p_{21} &= 16\cdot4 \quad ,, \\ p_m &= 16\cdot6\times10^{-7} \text{ sec.} \end{aligned}$$

From simple inspection of Table XVIII above, it is clear that the clock rate was very uneven, though the mean of the first pair is not very greatly different from the mean of the second pair of observations.

Apart from this systematic error, it is clear from analysis of Table XIX, which gives the differences of the mean from the individual pendulums, the residual differences and their squares, that other important errors are present.

TABLE XIX.

	M_p—5.	M_p—7.	21—M_p.
	4567×10^{-7} sec.	4867×10^{-7} sec.	9434×10^{-7} sec.
	96	53	48
	90	55	44
	90	71	60
Mean	4586	4862	9446

	v.	$(vv.)$	v.	$(vv.)$	v.	$(vv.)$
	-19×10^{-7} sec.	361	$+5\times10^{-7}$ sec.	25	-12×10^{-7} sec.	144
	+10	100	−9	81	+ 2	4
	+ 4	16	−7	49	− 2	4
	+ 4	16	+9	81	+14	196
$\Sigma(vv)$		493		236		348

The probable errors of a single difference are therefore, for :—

	$M_p - 5$	$8\cdot6\times10^{-7}$ sec.
	$M_p - 7$	$6\cdot0$,,
	$21 - M_p$	$7\cdot3$,,
the mean of which is		$7\cdot3\times10^{-7}$ sec.

The high value may be due to unevenness of clock rate during the short period occupied in swinging all three pendulums, but the unsatisfactory conditions in which the observations were made are clearly responsible in some measure.

As will be seen later, it is necessary to neglect the observations made with pendulum No. 5 in arriving at the final result.

Latitude, 77° 38′·4 S. *Longitude*, 166° 24′·1 E.

Height above mean sea-level, 8 *feet*.

One of the problems which required speedy solution after our return from sledging in the late autumn was the building of a suitable shelter in which the pendulum observations at the base station could be made. Unfortunately, there was available neither wood for the erection of a hut, nor any space in the living-hut itself. In these circumstances, the only alternatives were to build a hut from cases full of stores, or to dig a cave in an ice or snow-drift.

Choice was made of the latter alternative, and the same snow-drift consolidated to ice, which made so efficient a magnetic cave, was also chosen as the site of the pendulum cave. The two caves were about 100 feet apart.

By the end of May, the cave was ready and the instruments installed. A diagram of the cave is shown in Fig. 3. It was 6 feet high throughout, 14 feet long and 5 feet

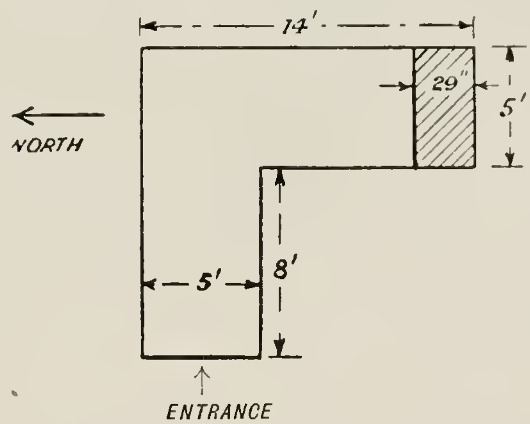

Fig. 3. Diagram showing dimensions and orientation of Ice Cave.

broad, and was approached by means of a narrow passage 8 feet long at right angles to the main chamber. The cave was dug originally into the perpendicular ice cliff left at the water's edge after the summer thaw, but gradually this became so drifted up that it could only be entered by a long staircase cut down to the entrance through the drifted snow. As each blizzard used to fill this staircase-like descent, it finally became a matter of considerable labour to keep the entrance clear.

At the far end of the ice chamber, the whole of the ice had not been removed—a solid block of ice being left, 75 cm. high by 73 cm. broad and 160 cms. wide, with only the upper part removed. This served as a very efficient and rigid pedestal for the support of the pendulum stand, and worked very satisfactorily. (Plate 1.)

To support the pendulum stand on the ice surface without danger of a change of level, due to sinking in of the small base plates provided under the levelling screws, these base plates were replaced by solid iron ones 4 inches square. This was found quite sufficient to prevent any noticeable sinking of the instrument. The iron base plates were firmly cemented in place by warming them, allowing them to melt a little of the ice and then become frozen tightly in place.

As stand for the coincidence apparatus two wooden cases were used—one above the other, firmly cemented to the ground and to one another by a mixture of snow and water. A small oil lamp was at first used as a source of illumination for the flashes, but was later replaced by a small electric lamp run from a set of dry batteries placed in a box padded with seaweed. This prevented the freezing of the cells during the time of observation.

At first, an attempt was made to run the break circuit clock "S.C." in the cave itself, but it was found impossible to keep it going for more than a few hours after setting up. At the end of that period, the works became cold and the clock ceased to go. This was due to the great viscosity of the oil at the low temperature prevailing in the cave, and though it might have been obviated by the use of extra driving weights, it was not thought advisable to do this.*

The clock was finally hung on the wall of the main hut close to the box chronometers, and the "time" was transmitted to the cave by the help of another observer and by the use of portable telephone sets supplied by the National Telephone Co. (Plates 2 and 3.)

This was found to work fairly satisfactorily as, by a suitable arrangement of the connections, it was possible for the observer calling the time from the clock in the hut to hear the beats made by the action of the coincidence apparatus ; and these, of course, were also heard by the observer in the cave. The proper numbering of the clock beats was therefore fairly easily assured, though mistakes of one second or of ten seconds quite frequently occurred owing to frosting up of the telephone by the observer's breath.

Four wires were required to make the necessary electrical connection with the pendulum cave—two for the telephone and two for the coincidence apparatus. Accumulators formed the source of supply of the current.

One of the most serious of the difficulties connected with work in the pendulum cave was due to the lowness of the temperature. During the observations, the temperature of the ice walls of the cave varied from $-20°$ to $-30°$ C. ; and, owing to the small

* It is essential that all chronometers, clocks, thermographs, etc., intended for use at very low temperatures should be as free as possible from any oil.

cubic capacity of the cave, it was not possible to obtain a steady temperature by artificial heating. The first difficulty met was due to the frosting of all the mirror and lens surfaces by the breath of the observer. Thus, the operations of levelling the apparatus, determining the flexure correction and placing the pendulums in position, so covered the prisms, agate planes, and the pendulums themselves with hoar-frost, that one could get no proper reflection of the light from the pendulum mirrors. Another possible source of error was due to changes in the period of the pendulums due to the hoar-frost accumulated on them.

The operations finally adopted were, in order :—

(1) Levelling.

(2) Determination of flexure correction.

(3) Placing pendulums in position with $CaCl_2$, or P_2O_5, in the case.

(4) Wait of about two weeks while the mirrors cleared.

In adopting this procedure, it was necessary to assume that, during the two weeks wait, no serious change of level or change in the flexure correction occurred, and that, by the time the mirrors were clear of hoar-frost, the pendulums themselves were also clear. Observations were then made in the usual way and the flexure correction redetermined at the end of the series.

A minor trouble consisted in the frosting of the telescope object glass and eyepiece, and of the windows in the cover of the pendulum stand, so that these had to be frequently cleaned during the course of the observations.

A much more serious difficulty lay in the large temperature changes as the observer entered and left the cave, due to the smallness of its size. For this reason, immediately the first readings had been made, the observer left the cave and only re-entered it as the second set of readings became due. The uncertainty in the observed temperature is moreover intensified by the position of the dummy pendulum, which is not hung as are the pendulums it is supposed to represent, but rests on a brass disc in direct connection with the large metal base of the instrument. It is clear that, in these unfavourable circumstances, the march of temperature in the pendulums is probably not at all well represented by the reading of the thermometer in the pendulum stand.

Equally serious was the large temperature gradient in the cave due to gradual conduction from the surface through the ice. At the time the cave was first built, the temperature (after the warmth of the summer) cannot have been many degrees below freezing-point, but, on the inception of winter conditions, a considerable temperature gradient was produced. Even at the time of the first measurements this amounted to 3° C. per metre.

A further irregularity in the readings was unfortunately furnished by the behaviour of the coincidence apparatus here and subsequently. This was shown in the following way :—In observing the course of successive flashes across the cross wire of the telescope, under normal conditions, the flashes in the vicinity of the cross wire should be equally spaced. At times, however, it was found that the spacing was exceedingly irregular and, in the extreme case, a flash might be so displaced as to appear to move backwards. The cause of this is not easy to determine. That the low temperature in the cave was not the sole cause of the trouble seemed clear from the fact that the coincidence apparatus did not work quite satisfactorily even under the more favourable temperature conditions of the second year, though undoubtedly the variations were of much smaller magnitude in these later observations. The electrical connections appeared to be quite good, and one is forced to the conclusion that irregularity in the action of the coincidence spring or of the clock contacts was the cause of the anomalous results noted above.

For this reason, it was decided to devise a better form of apparatus which would have no moving parts, and which would, therefore, not be subject to the same defects as this apparatus. Unfortunately, there was no gear suitable for making such a piece of apparatus, so one had to be content to do the best possible with the coincidence apparatus, and merely to ensure that the necessary parts of the new design should be waiting on the return to New Zealand and be available for subsequent work.

Rates of chronometers.—The clock used was the pendulum clock lent to the Expedition known as " S.C." It was hung on the wall of the living-hut close to the chronometer corner, and was daily compared, by the method of coincidences, with a mean time box chronometer by Kullberg. This was denoted by the letter " E," and was itself rated fortnightly by Commander Evans by sights on stars east and west.* Considerable difficulty was experienced with the clock " S.C." as regards irregularity of rate, partly, no doubt, due to the fact that the steel strip holding the pendulum had been broken in transit from Potsdam to Christchurch, and had to be replaced by a strip made by a local jeweller in Christchurch. Another serious difficulty was caused by a tendency of the hut to shift on its foundations and thus throw the clock out of the vertical. On one or two occasions, indeed, the hut shifted so much from the level that the escapement was unable to act on one side of the escapement wheel, owing to the great difference in the amplitudes of the pendulum on either side of the centre.

The history of the clock in the winter of 1911 is as follows :—On June 17th, the clock was set up on the wall of the hut and was running smoothly by the 21st. It went satisfactorily with a decreasing rate until July 15th, when the weights on the pendulum were altered. From July 18th to 22nd, it ran in an unsatisfactory manner and, on the 22nd, a new steel strip (a spare one made in New Zealand) was put in the place of the old one. By July 23rd, it was again running smoothly, and kept a fairly constant rate by comparison with " E " until it stopped on the 31st. On this date, " the clock was found badly off the vertical with the driving weight touching the side of the case and the escapement lever out of gear."

The clock was rehung, and from August 1st to 3rd maintained a constant rate, but, on the 3rd, was found stopped in the same manner as before.

* Altitudes by sextant.

The clock was tried next on a wooden box filled with sand and gravel, but worked even less satisfactorily here, so was replaced on the wall on August 9th. From the 12th to the 21st, the clock kept a very even rate, but stopped on the latter date for some unknown reason. From August 24th to September 2nd, it kept a fair rate and was put out of commission on September 3rd.

It is unfortunate that, during the first two series of observations at Cape Evans, a more regular comparison was not made between "S.C." and "E," as later "E" was found to have an extraordinarily constant rate. During 1912, the total range in its rate was from $-0 \cdot 2$ sec. to $+0 \cdot 2$ sec. per day. In order to gain a fair idea of the value that can be put on the comparison with "E," the daily difference—"S.C." gaining on "E" per 24 hours mean time—is put down for the days when it was working satisfactorily.

It has been mentioned that a value of the rate of "E" was obtained from observations of stars east and west: this furnished an indirect means of checking the accuracy of the daily rates of "S.C." as determined by myself with the portable transit instrument lent to the Expedition.

June 22–23	... ...	"S.C."–"E" 237·0	secs. in 24 hours.	
,, 23–24	... ...	237·1	,,	
,, 24–25	... ...	237·3	,,	
,, 25–26	... ...	236·5	,,	
,, 26–27	... ...	236·6	,,	
,, 27–28	... ...	235·7	,,	
,, 28–29	... ...	235·8	,,	
,, 29–30	... ...	236·4	,,	
June 30–July 1 ...	... ...	236·1	,,	
,, 1–2...	... ...	236·1	,,	
,, 2–3...	... ...	236·7	,,	
,, 3–4...	... ...	233·0	,,	Blizzard starts.
,, 4–5...	... ...	232·0	,,	
,, 5–6...	... ...	232·0	,,	
,, 6–7...	... ...	231·9	,,	
,, 7–8...	... ...	232·2	,,	
,, 8–10	... ...	232·0	,,	
,, 10–11	... ...	231·4	,,	
,, 11–12	... ...	230·5	,,	Blizzard starts.
,, 12–13	... ...	230·2	,,	
,, 13–14	... ...	230·2	,,	
,, 14–15	... ...	229·6	,,	
,, 24–25	... ...	243·0	,,	
,, 25–26	... ...	242·6	,,	
,, 26–27	... ...	242·9	,,	
,, 27–28	... ...	243·3	,,	
,, 28–29	... ...	243·5	,,	
,, 29–30	... ...	243·6	,,	

		Clock reset.
Aug.	12–13	"S.C."–"E." 237·1 secs. in 24 hours.
,,	13–14	237·1 ,,
,,	14–15	237·0 ,,
,,	15–16	237·2 ,,
,,	16–17	237·0 ,,
,,	17–18	236·9 ,,
,,	18–19	237·0 ,,

The transit instrument was of a very old pattern by Troughton and Simms, and was furnished with iron standards which could be screwed tight to a wooden box or other pillar. The lens was of $1\frac{5}{8}$-inch aperture and focal length about 23 inches. The lens should have been recemented before leaving England. A striding level of length 12 inches was provided, and was fitted with a new chambered level tube in London. Unfortunately, the instrument reached the dock only a few hours before our departure, and the level tube was then found to be already broken. Dr. Farr, however, very kindly came to the rescue in Christchurch with the loan of another striding level; but this also was found to be cracked at one end on arrival at Winter Quarters. The end of the tube was therefore cut off and plugged with a rubber cork. Later, the other end of the tube also cracked and was also furnished with a rubber cork. Finally, the level cracked down the centre and the fragments of glass were discarded. This, however, did not occur until the end of the first year's observations at Cape Evans, so that the level plugged with two corks was used during the whole of the first year. This suffered from the defect that the spirit, in spite of our best efforts, slowly leaked out, and the bubble became of unmanageable size after about five days' use. At the end of this period it must therefore be dismantled for refilling.

The diaphragm of the transit instrument was of glass—ruled with 5 vertical wires and 2 horizontal. The equatorial intervals between the wires were approximately 15 seconds each. All wires were observed with each star as there was not sufficient time to reverse the instrument.

The screws for the adjustment of collimation were very worn, as also those for adjustment of focus, with the result that they could not be properly tightened. As a consequence, it was early found that large changes in collimation were continually occurring during the period of observation, so that the time results were discordant.

The instrument was furnished with side axis illumination and with a small oil lamp, but, as the wind was nearly always fairly strong during observations, the lamp had continually to be relighted. It was therefore replaced by a small electric lamp run from dry cells, packed with insulating seaweed in a large box. This box was brought out from the warm hut at the start of the observations and taken back at the close.

The most serious defect of the instrument was due to wear of the pivots, or possibly to an actual "kink" in the axis. Thus, if the instrument was levelled when pointing south, on transiting the telescope to point north, it was now considerably out of level. At inclinations of the telescope to the horizontal, the level readings were different again

—the level readings varying with the altitude in quite an irregular manner. As a result of this, observations of circumpolar stars for the determination of the azimuth correction could not be made, since, at this altitude, the position of the telescope prevented the use of the striding level.

Considerable difficulty was experienced at all times owing to the low temperature at which the observations were made—(from —40° C. up)—and owing to the almost constant wind. Apart from the serious annoyance caused by the low temperature in freezing the exposed parts of the observer, the difficulty of fogging of the lenses was met with in its worst form, so that these had to be constantly scraped in order to remove the hoar-frost due to the observer's breath. The amount of hoar-frost deposited was, of course, aggravated by the telephone method used in taking the time of passage of the star.

For the time determinations, one observer (Dr. Simpson, Commander Evans or Mr. Debenham) stood in the chronometer corner and, as the star became due, counted into the telephone the seconds indicated by "S.C.," so that these were heard properly numbered in the other telephone outside. (Plate 2.) The observer outside (hearing at the same time the beats of the clock in the telephone) had to pick up the seconds and, in order to be assured of the correct numbers, had to count a few aloud and then carry on with the counting mentally. If the numbers counted were incorrect, he was interrupted by the voice from the other end giving the correct numbers again. The time of passage of the star across the different wires was estimated from the apparent position of the star at the half-seconds preceding and following the actual transit of the star. The second and estimated fraction of a second were spoken through the telephone to the observer at the clock and put down by him. The same process was repeated for the transit over succeeding wires.

As the hoar-frost from the breath accumulated in the mouth-piece and ear-piece of the telephone and clogged it up, it became necessary as time went on to use more and more breath to make oneself heard, resulting in the formation of still more hoar-frost. Finally, on one occasion, such force of lung had to be used that the voice outside was distinctly heard inside the hut above the hum of conversation—but not through the medium of the telephone.

As, during the course of pendulum swings, it is impossible to stop the observations, amusing incidents occasionally occurred, as was the case on a certain Sunday when the singing of "Onward, Christian Soldiers" was punctuated by the statement that "twenty-one, twenty-two, twenty-three" from the man stationed at the clock, and remarks (not audible to the church-goers) about the wind and weather from the observer at the transit instrument.

The pillar on which the transit instrument stood was a case 14 inches square and 4 feet high, open at the bottom and filled with a mixture of sand and water frozen into a solid mass, itself frozen to the ground. At the bottom it was banked by a similar frozen cement. To the top of this was screwed a heavy oak block, 5 inches wide, $2\frac{1}{2}$ inches thick and 18 inches long, and to this again was screwed the standard of the transit instrument. During the second year, this box was replaced by one much heavier and more solid—a petrol case about 2 feet by 2 feet by 3 feet which was frozen to the ground in exactly the same way. The stand was placed a few feet to the north-west of the hut in order to get as much shelter as possible from the prevailing south-easterly winds. (Plate 3.)

The fixed mark for the transit instrument consisted of a wooden post 2 inches by 3 inches in section, placed upright on the frozen ground and surrounded by a heap of stones and sand cemented together and to the ground by frozen water. The post was perfectly rigid and acted quite satisfactorily during the cold winter months. Through the post, about $3\frac{1}{2}$ feet above the ground, was bored a hole $\frac{3}{4}$ inch in diameter. Behind this hole was nailed to the post a tin box cut away at the back, and with another much smaller hole ($\frac{1}{8}$ inch) bored in the tin to correspond approximately with the centre of the hole in the wood. In the tin box was placed a small oil bicycle lamp which shone through the hole and furnished the fixed mark used throughout the first series of observations. Owing to the necessity for sheltering the transit instrument in the lee of the hut, and to the fact that a few feet north of the instrument was the shore of McMurdo Sound, it was found necessary to put the fixed mark to the south of the transit instrument. Unfortunately, the furthest distance visible in that direction was only about 125 yards away. The fixed mark was therefore set up close to the magnetic hut and at an altitude of $4° \cdot 5'$ from the transit instrument. Owing to the small distance separating the fixed mark from the transit instrument, the light was not properly focussed and appeared as a bright spot of appreciable diameter surrounded by a set of concentric circles of light, of decreasing brightness as the distance from the centre increased. It was, however, quite easy to bisect the circles. Of greater importance was the fact that the standards of the transit instrument allowed a lateral movement of $\frac{1}{25}$ inch. This was of importance because of the closeness of the fixed mark, and the difficulty of always keeping the instrument in the same relative position. The angular value of $\frac{1}{25}$ inch in 125 yards is $1'' \cdot 8$, giving a possible error in time from this cause of $0 \cdot 12$ sec.*

This was a serious matter, but there seemed no way of avoiding the difficulty. The only other instruments that might have served for the observations for rate were the small 4-inch sledging theodolites and a 5-inch altazimuth instrument which had only a single cross wire and in which the telescope was transited by reversing in the wyes. Neither of these was furnished with a striding level.

As might be expected from the preceding account, the observations with different stars showed very considerable variations, though in general the observations of the passage of a single star over the different wires were in fair agreement.

A preliminary calculation of the time observations was made in the south, but, since our return to England, Mr. W. E. Curtis, lately of the Imperial College of Science and Technology, South Kensington, has checked the whole series, and it is his computations that are here used.

Several times during the course of the winter, preparations were made to start

* $0 \cdot 12$ sec. for equatorial stars. For high-declination stars this error would be much greater.

pendulum observations, and the preliminary observations for rate of "S.C." were made, only to be stopped by the clouding of the sky and the approach of blizzards. In fact, the only two sets of four clear days with no more than moderate wind, which occurred during the first winter from the time of setting up of the pendulums until the return of the daylight, were those on which the first two series of observations (A and B) were made.

Reduction of Time Observations.—In the reduction of the observations, Mayer's formula was used :—

$$T = U + i\frac{\cos(\phi \pm \delta)}{\cos\delta} \pm \frac{c}{\cos\delta} + K\frac{\sin(\phi \pm \delta)}{\cos\delta}.$$

In this, i, C and K represent respectively the values of the constants of inclination of axis, collimation and azimuth.

Owing to the fact that circumpolar stars could not be observed, there is very great difficulty in deciding what azimuth constant to apply. The figures deduced for the azimuth constant on different days in series "A" were indeed so poor that no mean value whatever could be assigned. A value of the azimuth has therefore been taken, deduced from observations on July 31st and Aug. 1st, 2nd and 3rd during series "B." The adopted value is A=10·0 sec. In series "A," the uncertainty is not of very great importance as practically the same stars were observed each night.

With this azimuth constant, the results of the observation from individual stars are as follows :—

TABLE XX.

Date.	*	Face.	Wire.	*c.*	Collimation	Azimuth.	t_l.	t.	a.	Dt.	Mean.
June 30	β-Or.	E	I	0·38	0·28	9·46	51·39	64·13	15·18	11·05	
,,	γ-Or.	W	V	from	0·28	10·00	60·86	70·58	21·05	10·17	
,,	ϵ-Or.	W	V	γ-Or.,	0·28	9·72	81·46	90·90	41·41	10·51	
,,	i' Scp.	E	V	ϵ-Or.,	0·37	11·56	61·49	75·60	24·55	(8·95)	10·50
,,	a-Or.	E	I	a-Or.,	0·28	10·04	59·89	70·21	20·82	10·61	
,,	γ^2-Sag.	W	I	&	0·32	11·04	46·34	57·70	8·09	10·39	
,,	ϕ-Sag.	W	I	γ^2-Sag.	0·31	10·90	47·46	58·67	8·46	(9·79)	
July 2	β-Or.	W	V	0·49	0·49	9·46	55·02	63·99	15·23	11·21	
,,	γ-Or.	W	V	from	0·49	10·00	60·61	70·12	21·10	10·98	
,,	ϵ-Or.	W	V	β-Or.,	0·49	9·72	81·06	90·29	41·46	11·17	
,,	i' Scp.	E	V	γ-Or.,	0·61	11·56	60·96	71·88	24·56	(12·68)	11·13
,,	a-Or.	E	I	ϵ-Or.,	0·49	10·04	57·25	67·78	20·86	(13·08)	
,,	γ^2-Sag.	W	I	γ^2-Sag.,	0·57	11·04	45·31	56·92	8·11	11·19	
,,	ϵ-Sag.	W	I	ϵ-Sag.,	0·59	11·23	55·78	67·60	18·75	11·15	
,,	σ-Sag.	W	I	& σ-Sag.	0·51	10·82	85·08	96·44	47·50	11·06	
July 3	β-Or.	W	V		1·60	9·46	56·14	64·00	15·25	11·25	
,,	γ-Or.	W	V		1·59	10·00	61·55	69·96	21·12	11·16	
,,	ϵ-Or.	W	V	1·58	1·58	9·72	82·39	90·53	41·47	10·94	
,,	i' Scp.	E	V	from	2·07	11·56	61·07	70·56	21·57	(14·01)	11·11
,,	a-Or.	E	I	β-, γ-,	1·59	10·04	55·31	66·94	20·87	(13·93)	
,,	γ^2-Sag.	W	I	ϵ-Or. &	1·83	11·04	41·00	56·87	8·11	11·24	
,,	ϵ-Sag.	W	I	γ^2-, ϵ-,	1·92	11·23	54·61	67·76	18·76	11·00	
,,	ϕ-Sag.	W	I	& ϕ-Sag.	1·78	10·90	44·76	57·44	8·51	11·07	
,,	σ-Sag.	E	V		1·77	10·82	84·32	93·37	47·51	12·11	

The following note has been made by Mr. Curtis on the method of reduction of the observations :—

"I have reduced each set separately first, and tried to get a value for the azimuth (neglecting collimation). Then I took the mean of the lot as the true azimuth, and applied this to all the results (except those showing a very great discordance). It was then usually possible to obtain a fairly reliable value for the collimation, which appears to be fairly definite for each set, although liable to irregular disturbances. Finally, I have taken the mean of the most concordant results, neglecting those showing large deviations from the mean (frequently the case with high stars)."

The most noticeable point in Table XX is the large number of star observations which have been excluded in arriving at the mean result. Such a procedure could hardly be recommended, did we not know that there were large instrumental errors liable to occur with this instrument, and of almost unknown magnitude. The observations of July 1st are hopelessly inconsistent and have been neglected ; no collimation correction could here be deduced from the observations. On the other three days, it will be noted that the value of Dt deduced from i' Scorpii is always widely different from that deduced from the other stars, and that α Orionis does not give very good results. The inconsistency of the first may be explained by the fact that it is the single high star which has been observed. The poor results from α Orionis are probably due to the fact that this star has so low an altitude that it just skims the top of the Barne Glacier to the north, and is subject to lateral refraction. In the same way, ϕ Sag. and σ Sag. also skim the slope of the small hill called Vane Hill, and may possibly be subject to the same abnormal refraction.

If these four stars are neglected in obtaining the mean values of Dt on these days, there remains only a single observation of β Orionis which shows serious discordance. Unfortunately, however, if all four stars are neglected we are left on some days with too few observations for the calculation of rate, and it seems wiser to throw out only those observations which appear very inconsistent.

Clock rate.—It will be noticed that the actual observations give from—

June 30th to July 1st	.. .. ..	"S.C." losing	0·30	sec. daily.
July 1st to July 2nd	.. .. ..	"S.C." losing	0·32	,, ,,
July 2nd to July 3rd	.. .. ..	"S.C." gaining	0·02	,, ,,

Owing to the uncertainties of the work, it has seemed advisable to use the same clock rate throughout, and the mean of 0·20 sec. losing has been chosen. This corresponds to a correction to the time of swing of the pendulums of 12 sec. $\times 10^{-7}$.

The temperature was measured by Thermometer No. 41204. The corrections, deduced from the comparisons in May, 1910, and Oct., 1913, are taken as under :—

At	−20° C.	thermometer	reads	0·03° C. too low.
,,	−10° C.	,,	,,	correctly.
,,	0° C.	,,	,,	0·02° C. too high.
,,	+10° C.	,,	,,	0·02° C. too low.

The total range of temperature in the pendulum case was from $-22^\circ \cdot 75$ to $-25^\circ \cdot 21$ C., and the maximum change during observations was at the rate of $0 \cdot 6^\circ$ per hour, the corresponding change in temperature of the air in the cave being of the order of 2 to 3 degrees. That the range was not larger, is due to the fact that observations were always made in cold, clear weather when the temperature outside varied from about -30° C. to -40° C., so that the temperature could be kept reasonably constant by leaving the door (formed of sacking) open during the period of observation. In this series, the temperature shown by the thermometer in the dummy pendulum was estimated by eye to hundredths of a degree.

Barometer.—The density correction is calculated from the reading of the station barometer (No. 1157), corrected in the ordinary way and read about every hour. The total range during the series was from 734·6 mm. to 752·1 mm.

Hygrometer.—Observations of the percentage humidity of the air were not taken, the correction for the small amount of vapour being almost negligible.

Flexure.—Observations for the flexure correction were made as under :—

	Nos. 5 and 7.	No. 21.
June 19th	—	$20 \cdot 6 \times 10^{-7}$ sec.
July 3rd	—	23·1
,, 4th	$17 \cdot 2 \times 10^{-7}$ sec.	—
,, 5th	14·2	—
,, 6th	15·1	—
,, 7th	—	21·6
Mean	16	22
Probable error ..	$\pm 1 \cdot 0 \times 10^{-7}$ sec.	$\pm 0 \cdot 9 \times 10^{-7}$ sec.

16×10^{-7} sec. and 22×10^{-7} sec. have been taken as the corrections to be applied throughout.

In Table XXI is given the full analysis of the pendulum results of series A and, in Table XXII below, they are gathered together so as to show the behaviour of the individual pendulums.

TABLE XXII.

No. 5.		No. 7.		No. 21.		Mean.	
A.	B.	A.	B.	A.	B.	A.	B.
0·5079007	sec.	0·5078773	sec.	0·5093044	sec.	0·5083608	sec.
8991	999	769	771	043	044	601	604
977	964	721	702	012	032	570	566
952		683		053		563	
970	980	715	740	012	017	566	579
989		766		022		592	
Means 0·5078981 sec.		0·5078738 sec.		0·5093031 sec.		0·5083583 sec.	

The first glance at this Table shows that the observations are very discordant but, for a proper calculation of their probable errors, the v's and (vv)'s are put down in Table XXIII.

TABLE XXIII.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	26×10^{-7} sec.	676	35×10^{-7} sec.	1225	13×10^{-7} sec.	169	25×10^{-7} sec.	625
	10	100	31	961	12	144	18	324
	4	16	17	289	19	361	13	169
	29	841	55	3025	22	484	20	400
	11	121	23	529	19	361	17	289
	8	64	28	784	9	81	9	81
Σ (vv) ...		1818		6813		1600		1888

From this Table, we find the probable error of a single observation to be—

$$e_5 = 12\cdot7\times10^{-7} \text{ sec.}$$
$$e_7 = 24\cdot6$$
$$e_{21} = 11\cdot9$$
$$e_m = 12\cdot9\times10^{-7} \text{ sec.}$$

Also, for the probable error of the mean result :—

$$p_5 = 5\cdot1\times10^{-7} \text{ sec.}$$
$$p_7 = 9\cdot8$$
$$p_{21} = 4\cdot8$$
$$p_m = 5\cdot2\times10^{-7} \text{ sec.}$$

These values of e_x and of p_x are large in comparison with those obtained at Potsdam, but hardly excessive in view of the difficulties inherent in work at such a station.

As before, to exhibit the magnitude of the observational error, we form the following Tables of the differences from the mean pendulum.

TABLE XXIV.

	M—5.	M—7.	21—M.
	4601×10^{-7} sec.	4835×10^{-7} sec.	9436×10^{-7} sec.
	4610	32	42
	4593	49	42
	4611	80	90
	4596	51	46
	4603	26	30
Mean	4602	4845	9448

TABLE XXV.

	M_p—5.		M_p—7.		21—M_p.	
v (vv) ...	1×10^{-7} sec.	1	10×10^{-7} sec.	100	12×10^{-7} sec.	144
	8	64	13	169	6	36
	9	81	4	16	6	36
	9	81	35	1225	42	1764
	6	36	6	36	2	4
	1	1	19	361	18	324
Σ (vv) ...		264		1907		2308

Calculating the probable errors from Table XXV, we get for the probable error of the difference—

M_p—5	$4 \cdot 9 \times 10^{-7}$ sec.,	comparing with	$e_5 =$	$12 \cdot 7 \times 10^{-7}$ sec.
M_p—7	$13 \cdot 0$,,	,,	$e_7 =$	$24 \cdot 6$
21—M_p	$14 \cdot 3$,,	,,	$e_{21} =$	$11 \cdot 9$
mean value ..	$10 \cdot 7 \times 10^{-7}$ sec.	mean value		$16 \cdot 4 \times 10^{-7}$ sec.

The mean value $10 \cdot 7 \times 10^{-7}$ sec. compares with $3 \cdot 1 \times 10^{-7}$ sec. for the first Potsdam observations, and $2 \cdot 5 \times 10^{-7}$ sec. for the second.

This measure is 3–4 times as great as that for the Potsdam observations and suggests that the coincidence apparatus was probably the cause of no small part of the large probable error. At the same time, it must be remembered that a source of error which is included in this estimate, is that due to *variations*—chiefly in temperature and clock rate—during the progress of a single set. These may have been considerable in the series.

CAPE EVANS, SERIES B, 1911.

This series of observations was made on August 16th, 17th and 18th in the same ice cave as Series A, but with improvements of the apparatus in certain details.

Time observations.—For these observations the oil lamp of the old fixed mark was replaced by a small 4-volt incandescent lamp, screwed to the front of the same post as was previously used, and actuated by a set of dry cells kept in an (heat) insulated box. This gave a much more regular light for the " fixed mark " and could not be blown out by the wind.

The transit instrument was improved by the simple device of soldering the eyepiece in place, together with the sliding tube for focussing. The level remained unchanged with a rubber cork in each end.

Pendulum apparatus.—For the better reading of the temperature in the dummy pendulum, an iron rod $\frac{1}{2}$ inch in diameter was frozen solidly into the shelf of ice in front of the pendulum stand and on it was fixed the microscope from a Wilson Portable Electroscope,* for reading the temperature more accurately. Thermometer No. 41204 was used in Series B.

In this series and in all observations after this date, the heavy brass disc on which the dummy pendulum rested was replaced by one of cork, in order that the temperature of the dummy might the more nearly approach the temperature of the pendulums themselves. These were of course hanging freely from the agate planes and not in any way in metallic connection with the stand.

Rate of Clock " S.C."—Star observations were made in the same manner as in Series A, but with somewhat better results. A similar method of reduction was used by Mr. Curtis as in the first series of observations. A value of the azimuth constant was determined for each day's observations (collimation neglected), the mean taken as the true azimuth, the sights recalculated and the collimation correction applied.

The azimuth constant deduced from the different days of observation gave on—

Aug. 15th	7·2 sec.	July 30th	10·4 sec.
,, 16th	9·1 ,,	Aug. 1st	10·0 ,,
,, 17th	9·0 ,,	,, 2nd	10·2 ,,
,, 18th	10·5 ,,	,, 7th	14·3 ,,
		,, 8th	8·7 ,,

As in the preceding series, the azimuth has been taken as +10·0 sec. throughout.

* Kindly lent by the Cambridge Scientific Instrument Co.

In detail, the results are put down in the following Table :—

TABLE XXVI.

Date.	*	Face.	Wire.	c.	Colli-mation	Azi-muth.	t_l.	t.	α	Dt.	Mean.
Aug. 8	η-Oph.	W	V	0·85 from all but ζ-C.M.	0·87	9·17	76·57	84·87	18·53	53·66	
,,	θ-Oph.	E	I		0·93	8·79	31·50	41·22	34·91	53·72	
,,	β-Col.	E	V		1·21	11·26	44·78	54·83	49·07	(51·24)	53·77
,,	ι-Oph.	E	I		0·86	9·41	65·73	76·00	9·96	53·96	
,,	γ^2-Sag.	E	I		0·98	8·52	64·85	74·35	8·15	53·80	
,,	μ-Sag.	W	V		0·91	8·97	87·25	95·31	29·04	53·73	
,,	ζ-C.M.	W	I		0·98	11·02	48·68	60·68	53·52	(52·84)	
Aug. 15	δ-Sag.	W	V	0·34 from δ- and λ-Sag., δ-C.M., η C.M.	0·39	8·53	75·20	83·34	20·59	57·25	
,,	λ-Sag.	W	V		0·37	8·77	86·01	91·44	31·42	56·98	
,,	ν-Arg.	E	V		0·46	11·78	54·73	66·05	1·79	(55·74)	
,,	ϕ-Sag.	E	I		0·38	8·68	63·58	72·64	8·63	(55·99)	57·13
,,	σ-Sag.	E	I		0·38	8·69	41·32	50·39	47·68	57·29	
,,	ϵ-C.M.	E	V		0·39	10·96	60·23	70·80	7·48	(56·68)	
,,	δ-C.M.	W	I		0·38	10·84	37·82	49·04	46·14	57·10	
,,	π-Arg.	W	I		0·42	11·37	50·61	62·40	59·43	57·03	
,,	η-C.M.	W	I		0·39	10·98	85·72	97·09	34·22	57·13	
Aug. 16	δ-Sag.	W	V	0·29 from all but π-Arg. & σ-Arg.	0·34	8·53	76·17	84·36	20·57	56·21	
,,	λ-Sag.	W	V		0·33	8·77	86·52	94·96	31·42	56·46	
,,	ν-Arg.	E	V		0·40	11·78	53·97	65·35	1·80	56·45	
,,	ϕ-Sag.	E	I		0·33	8·68	63·00	72·01	8·63	56·62	
,,	σ-Sag.	E	I		0·33	8·69	42·13	51·15	47·68	56·53	
,,	ϵ-C.M.	E	V		0·34	10·96	60·41	71·03	7·48	56·45	56·37
,,	δ-C.M.	W	I		0·33	10·84	38·92	50·09	46·14	56·05	
,,	π-Arg.	W	I		0·37	11·37	51·83	63·57	59·43	(55·86)	
,,	η-C.M.	W	I		0·34	10·98	86·54	97·86	34·22	56·36	
,,	σ-Arg.	E	V		0·40	11·76	76·19	87·55	23·52	(55·97)	
Aug. 17	λ-Sag.	W	V	0·20 from ν-Arg., ϕ-Sag., σ-Sag., & ϵ-C.M.	0·22	8·77	86·23	94·78	31·41	(56·63)	
,,	ν-Arg.	E	V		0·27	11·78	54·58	66·09	1·83	55·74	
,,	ϕ-Sag.	E	I		0·22	8·68	64·11	73·01	8·62	55·61	
,,	σ-Sag.	E	I		0·22	8·69	42·81	51·72	47·68	55·96	55·79
,,	ϵ-C.M.	E	V		0·22	10·96	60·94	71·68	7·51	55·83	
,,	π-Arg.	W	I		0·25	11·37	51·75	63·37	59·46	(56·09)	
Aug. 18	δ-Sag.	W	V	0·29 from $\delta\lambda\phi$-Sag., & ϵ-, δ-C.M.	0·34	8·53	76·06	84·25	20·55	56·30	
,,	λ-Sag.	W	V		0·32	8·77	87·19	95·64	31·40	55·76	
,,	ν-Arg.	E	V		0·40	11·78	53·67	65·05	1·87	56·82	
,,	ϕ-Sag.	E	I		0·33	8·68	63·83	72·84	8·61	55·77	55·96
,,	σ-Sag.	E	I		0·32	8·69	42·49	51·50	47·67	56·17	
,,	ϵ-C.M.	E	V		0·33	10·96	61·06	71·69	7·55	55·86	
,,	δ-C.M.	W	I		0·32	10·84	39·06	50·22	46·21	55·99	
,,	π-Arg.	W	I		0·36	11·37	51·64	63·37	59·49	55·12	
,,	σ-Arg.	E	V		0·40	11·76	76·51	87·87	23·58	55·71	

On Aug. 15th, the observations of E. Canis Minoris were marked at the time as bad and the whole set marked as fair ; the temperature was —37° F., the sky a bit hazy, with but little wind. On Aug. 16th, the set was slightly better and no observations were marked bad; temperature —40° F., slight wind at times. On Aug. 17th, the whole set is marked very bad; temperature —35° F., sky very hazy, very marked temperature changes alternately depositing crystals on the lenses and removing them again, marked refraction effects in the direction of the fixed mark. Owing to the haze over the sky, the stars were too faint for good work.

On Aug. 18th, $t = -40°$ F., sights marked good, little wind, clear sky.

In the above Table it will be noted that a number of star observations (in brackets) have been neglected, and to decide which ones were to be thrown out Chauvenet's Criterion was applied. It seems doubtful, however, if this method is quite allowable in observations such as those of Aug. 15th. Here, by successive applications of the method, three stars are thrown out, leaving only six sights from which a value of the rate is to be calculated.

The actual rate taken for this series is not the rate shown by these observations, but one arrived at in the following way. The observations of the 18th, appearing to be the best, are taken as correct; and the mean of the rates deduced from it and from the observations of the 15th and of the 16th is applied to the whole period.

(1) Aug. 15th	.. ..	$Dt = 57 \cdot 13$ sec.
(2) ,, 16th	.. ..	56·37 ,,
(3) ,, 17th	.. ..	— (neglected)
(4) ,, 18th	.. ..	55·96 sec.

From (1) and (4), the daily rate of " S.C. " is 0·39 sec. gaining, and from (2) and (4) 0·20 sec. gaining. The mean 0·30 sec. gaining is therefore applied over the whole period. (A)

The prime reason for assuming a constant rate for " S.C." lies in the comparisons with mean chronometer " E."

Thus " S.C." gained on " E " from the 15th to the 16th..	237·03 sec.		
,, ,, ,, 16th ,, 17th..	237·01 ,,	mean 237·00 sec.	
,, ,, ,, 17th ,, 18th..	236·96 ,,		

This assumption seems a fair one, as it is exceedingly unlikely that the two chronometers would both be erratic to the same extent.

During August, " E " was going very well, observations by Commander Evans giving from—

July 27th to Aug. 2nd	.. .. ..	" E " 0·071 sec. losing daily.
Aug. 2nd to Aug. 15th	.. .. ..	0·144 ,, ,, ,,
Aug. 15th to Aug. 29th	.. .. ..	0·144 ,, ,, ,,

The following calculation can then be made for this period—

"S.C." — "E"	= 237·00	sec.	
M.T. — "E"	= 0·144	,,	
"S.C." — M.T.	= 236·856	,,	
S.T. — M.T.	= 236·555	,,	
"S.C." — S.T.	= 0·301	,, gaining daily.	(B)

The agreement between (A) and (B) is no doubt fortuitous, but, at least, it enables us to say with fair reason that the probable error of the clock rate is not large.

Temperature.—The variations of temperature in the cave were of lesser magnitude than in Series A, the total range being from $-26°\cdot32$ down to $-26°\cdot99$ or only $0\cdot6°$ C. The maximum rate of variation indicated by the pendulum thermometer is $0°\cdot18$ C. per hour on Aug. 16th. Thermometer No. 41204 was again used in this series and the same corrections as before applied to the observed readings.

Barometer and Hygrometer.—As in Series A.

Flexure.—Observations for flexure were made only twice—once before and once after the swings—as follows :—

	Nos. 5 and 7.		No. 21.
	$15\cdot9\times10^{-7}$ sec.		$19\cdot3\times10^{-7}$ sec.
	$15\cdot1$		$21\cdot6$
means	16×10^{-7} sec.	and	20×10^{-7} sec.

Results.

In Table XXVII, are given the full results of the observations and, in Table XXVIII, the readings of the individual pendulums are put down in more convenient form.

Table XXVIII.

No. 5.	No. 7.	No. 21.	Mean.
0·5079028 sec.	0·5078795 sec.	0·5093086 sec.	0·5083636 sec.
9000	764	071	612
(8938)	767	(139)	615
9010	752	052	605
8999	771	071	614
9010	759	055	608
Means 0·5079009 sec.	0·5078768 sec.	0·5093067 sec.	0·5083615 sec.

Table XXIX.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	19×10^{-7} sec.	361	27×10^{-7} sec.	729	19×10^{-7} sec.	361	21×10^{-7} sec.	441
	9	81	4	16	4	16	3	9
			1	1			0	0
	1	1	16	256	15	225	10	100
	10	100	3	9	4	16	1	1
	1	1	9	81	12	144	9	49
Σ (vv) ...		544		1092		762		600

From Table XXIX, the probable errors of a single observation by any pendulum are—

or $e_5 = 7\cdot8\times10^{-7}$ sec. $\quad p_5 = 3\cdot9\times10^{-7}$ sec.

$e_7 = 9\cdot9 \quad p_7 = 4\cdot4$

$e_{21} = 9\cdot2 \quad p_{21} = 4\cdot6$

$e_m = 7\cdot3\times10^{-7}$ sec. $\quad p_m = 3\cdot3\times10^{-7}$ sec.

The probable error of these results is hardly more than half that calculated from the observations in Series A.

As before, Tables XXX and XXXI are formed to facilitate the formation of our measure for the accuracy of the observational work.

Table XXX.

	M_p-5.	M_p-7.	$21-M_p$.
	4608×10^{-7} sec.	4841×10^{-7} sec.	9450×10^{-7} sec.
	4612	48	59
		48	
	4595	53	47
	4615	43	57
	4598	49	47
Mean ...	4606	4847	9452

TABLE XXXI.

	M_p-5.		M_p-7.		$21-M_p$.	
$v\ (vv)$ ...	2×10^{-7} sec.	4	6×10^{-7} sec.	36	2×10^{-7} sec.	4
	6	36	1	1	7	49
			1	1		
	11	121	6	36	5	25
	9	81	4	16	5	25
	8	64	2	4	5	25
$\Sigma\ (vv)$ ...		306		94		128

Giving for the probable error of a single difference

$$\begin{aligned} \text{for } M_p-5 &= 5\cdot8\times10^{-7} \text{ sec.} \\ M_p-7 &= 2\cdot9 \\ 21-M_p &= 3\cdot8 \end{aligned}$$

The mean of these ($4\cdot2\times10^{-7}$ sec.) is less than half the corresponding figure obtained from an analysis of the results of series "A."

CAPE EVANS, SERIES C.

JULY 13TH TO 16TH, 1912.

Height above sea-level—10 feet.

In view of the disappointing discordance of the results of Series A and B, not only as regards the individual observations of swing, but also as regards the means of the different series, it was decided that a revolutionary change must be made in the method of observation.

Apart from the large errors in time determination which were due almost wholly to irremediable defects in the transit instrument, it was clear that low temperature was the cause of a great part of the difficulty. It was obvious, in the first place, that the low temperature in the ice cave had a very unfavourable effect on the action of the coincidence apparatus. Possibly greater, was the uncertainty due to deposition of hoar-frost on the agate planes and on the pendulums themselves.

It was decided, therefore, to build a small hut of petrol cases covered with rubberoid and canvas, which was to be artificially heated during the observations. By March 17th, the hut of heavy cases, still containing petrol and weighing some 150 lb. each, was entirely built except for the roof, the cases being tightly nailed together. No opportunity to put on the canvas roof occurred and, on the 20th, a blizzard levelled the embryo hut. On the 23rd, it had been restored to its former state and was demolished again by wind on the 27th. On this occasion, a heavy 80-lb. wooden beam nailed up as a ridge pole was torn off and hurled a full 40 feet. On the 28th, the hut was finished and the canvas roof put on, the whole being well banked with snow. Succeeding blizzards were unable to move the hut. It was, however, reluctantly abandoned after several days' trial, as it was found impossible to keep the hut at a workable temperature, or even to keep it free from drift snow.

The only alternative was to place the pendulum apparatus in the living hut itself. This had the great advantage that the temperatures were above freezing-point, and that there would be no danger of short circuits or breaks in the wires from the clock to the coincidence apparatus. In the preceding series, this had caused trouble owing to the difficulty of locating defective wires under 5 feet of snow. The only objection connected with the use of the pendulums in the hut seemed to be the trouble of finding a rigid base on which to place the pendulum stand. Owing to our reduced numbers now, the hut was quite large enough to accommodate the pendulum instruments, and Debenham kindly lent the use of his photographic dark-room for the work. This was of peculiar advantage, in that the dark-room formed a separate compartment whose temperature could be kept fairly constant by closing the door giving access to the living-room.

In the floor of this dark-room, a large hole about 2 feet square was cut, and the frozen volcanic sand attacked with picks until an excavation about a foot deep was made in the frozen mixture. A large kenyte boulder just able to enter the hole in the floor was next sledged into the hut and placed in position in the hole prepared for it. The top surface of this was prepared roughly flat and was level with the floor of the hut. Around the boulder was next placed a quantity of the volcanic sand and a pail of water poured over it and allowed to freeze. At intervals during three of four days, sand and water were added (as fast as the water could be melted on the cooking range), until the boulder was firmly cemented to the ground and to about a cubic yard of the volcanic gravel.

Conical holes were next drilled into the surface of the boulder for the reception of the levelling screws of the stand, and the hole in the floor covered with a loose double layer of Burberry cloth. This was designed to keep out draughts from below, without making rigid connection between the boulder and the unstable floor of the hut. Small holes in the wind-proof covering permitted the levelling screws to rest directly on the boulder. The next step was to make a more rigid support for the pendulum clock, and another hole was made in the floor, and a heavy solid pillar of Jarrah wood, 1 foot wide and 6 inches thick, was cemented into the ground with water and gravel. A heavy screw supported the clock. In this position, the clock hung for several months without stopping (being now independent of changes in level of the hut).

That the temperature of the pendulums might remain more constant, a small square was cut from one of the walls of the dark-room, and the flashes from the coincidence apparatus observed through this hole in the wall. Through the same hole, the face of the sidereal clock could also be seen. Owing to the low position of the pendulum stand, the coincidences had to be observed by lying at full length on the floor, a slight personal inconvenience being the only difficulty involved. A diagram of the connections in this corner of the hut is given below.

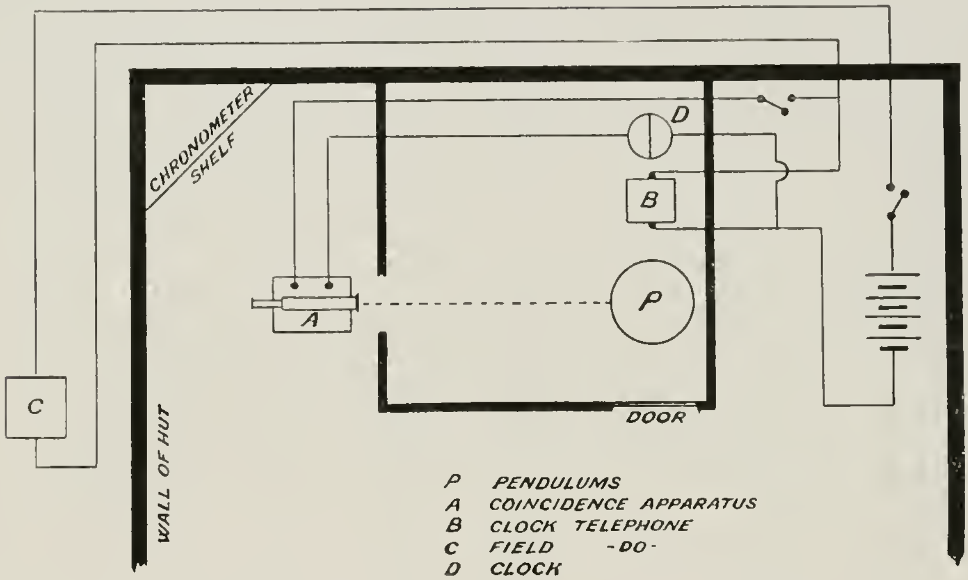

Fig. 4. Diagram showing arrangement of pendulum apparatus within the Hut.

The dummy pendulum, as before, rested on a cork disc placed upon the stand of the instrument. In the hope of getting a more accurate value of the temperature of the pendulum rod, two more thermometers were hung beside the dummy pendulum (not touching it), the one upright and the other reversed. These were arranged with their bulbs at equal distances on either side of the mid-point between the centres of gravity and of suspension. All three were read by the same microscope as was used in series B, and which slid vertically on a heavy retort stand.

The arrangements for time observations were practically the same as in the preceding year, except that a much heavier and more rigid base for the transit instrument was substituted, in the form of a petrol case full of a cement of gravel and water. The final dissolution of the level borrowed in New Zealand made it necessary to use a much less sensitive level fixed above the old broken striding level and taken from one of the 4-inch theodolites. Plate 4 shows the form in which this was arranged. Owing to the lack of sensitiveness, a further source of error in the level correction was in this way introduced. The results of the time observations are put down below in Table XXXII.

TABLE XXXII.

Date.	*.	A. +	Azimuth. −	t_1.	t.	α.	dt.	Means. Sec.
July 12th	α-Arg.	1·260	8·89	99·42	90·53	58·28	27·75	
,,	ν-Arg.	1·176	8·39	44·11	35·81	3·13	27·32	
,,	τ-Arg.	1·234	8·70	84·68	75·98	42·57	27·59	
,,	ϵ-C.M.	1·094	7·71	49·91	42·20	9·49	27·29	27·21 ± 0·25
,,	δ-C.M.	1·084	7·65	89·05	81·40	48·26	26·86	
,,	π-Arg.	1·136	8·00	42·46	34·46	1·22	26·76	
,,	η-C.M.	1·096	7·72	77·10	69·38	36·31	26·93	
July 14th	α-Col.	1·120	7·90	67·85	59·95	27·32	27·37	
,,	β-Col.	1·126	7·97	90·94	82·97	50·84	27·87	27·48 ± 0·20
,,	ζ-C.M.	1·100	7·76	36·17	28·41	55·56	27·15	
,,	ν-Arg.	1·176	8·30	43·94	35·64	3·15	27·51	
July 15th	β-Phen.	1·206	8·52	50·09	41·57	11·42	(29·85)	
,,	γ-Phen.	1·182	8·32	73·87	65·55	34·38	(28·83)	27·88
,,	ν-Ceti.	1·060	7·48	92·39	84·91	52·80	27·89	
,,	κ-Forn.	1·074	7·59	71·79	64·20	32·06	27·86	
July 16th	ϕ-Sag.	1·086	7·68	52·37	44·69	12·75	28·06	
,,	σ-Sag.	1·084	7·65	91·43	83·78	51·76	27·98	28·04 ± 0·08
,,	ζ-Sag.	1·102	7·78	44·02	36·24	64·16	27·92	
,,	τ-Sag.	1·092	7·70	69·64	61·94	30·14	28·20	

Date.	L.M.T.	dt.	Interval.	Loss.	Daily Rate (losing).
July 12th ...	11·30 p.m.	27·21 sec.			
			1·96 d.	0·27 sec.	0·14 sec.
,, 14th ...	10·30 p.m.	27·48 ,,			
			0·81	0·40 ,,	0·49 ,,
,, 15th ...	6 p.m.	27·88 ,,			
			0·71	0·16 ,,	0·23 ,,
,, 16th ...	11 a.m.	28·04 ,,			

The uncertainties in the determination of azimuth constant in the other two series decided me to abandon all hope of a proper determination of this constant, and to make use only of low stars to the south, *i.e.* just a little above the fixed mark. By confining one's observations to stars of the same or almost the same southerly declination, the azimuth does not need to be known with any great exactitude, so long as one can make the apparently permissible assumption that the azimuth of the fixed mark remains unchanged in the short period during which observations are being made.

Actually the azimuth correction has been found, from calculation of the observations, to be small but of uncertain sign; and throughout has been applied the same correction $K=-7\cdot05$ sec. (as also in series D). The value of this azimuth constant has been calculated from local time sights of π Argus on Aug. 13th, which has a probable error for the determination of $\pm 2\cdot0$ secs.

The actual error introduced by an uncertainty in the value of the azimuth constant, though appreciable, is not much greater than the probable error of the sights themselves. From Table XXXII we have the following values for dt:—

				losing.	
July 12th ..	27·21 sec. ±0·25 ;	mean value of A =	−8·12 sec.. rates	0·14	(a)
,, 14th ..	27·48 ,, ±0·20	,,	−7·98 ,,	—	
,, 15th ..	27·88 ,,	,,	−7·98 ,,	0·49	
,, 16th ..	28·04 ,, ±0·08	,,	−7·70 ,,	0·23	

Therefore, if an error of 7·05 sec. in the azimuth constant has occurred, the azimuth will now be zero, and the corresponding time calculation—

	dt	rates
July 12th	19·09 sec.	
		.. .. 0·21 sec. losing.
,, 14th	19·50 ,,	
		.. .. 0·49 ,,
,, 15th	19·90 ,,	
		.. .. 0·62 ,,
,, 16th	20·34 ,,	

In order to keep a better check on the possible irregularities in the action of "S.C.," during the two series C and D, the pendulum clock was compared five times daily with each of the three mean time box chronometers "E," "F" and "H." By this means it was hoped, if the rate of "S.C." did not remain constant, to pick out the times at which the rate changed, and thus be able to apply a rate appropriate to the period during which the pendulums were swinging. As an illustration of the working of this method, we find by comparison of "S.C." and "E." at the time of sights that:—

(1) For the first pair of sights, July 12th to 14th, "S.C." was gaining on "E" 236·32 sec. daily.
(2) For the second, July 14th to 15th, "S.C." was gaining on "E" 235·81 sec. daily.
(3) For the third, July 15th to 16th, "S.C." was gaining on "E" 236·15 sec. daily. (b)

From (a) we see that

(1) "S.C." was losing 0·14 sec. daily
(2) ,, ,, 0·49 ,, ,,
(3) ,, ,, 0·23 ,, ,, in the same intervals. (c)

From (*b*) and (*e*) we find that—

(1)	" E " was losing on sidereal time			236·46 sec. daily.			(*d*)
(2)	,,	,,	,,	236·30	,,	,,	
(3)	,,	,,	,,	236·38	,,	,,	

We may therefore take it that " E " chronometer was probably keeping a fairly steady rate.

Further, from a consideration of the values of " S.C."—" E " at the five chosen periods of the day, we find that " S.C." changed its rate (" E " assumed constant) between the a.m. and p.m. sights on July 14th, and again between the p.m. sights of July 15th and the a.m. sights of the 16th. Thus, we apply the correction 0·14 sec. losing to the first three pendulum observations, 0·49 sec. losing to the next three, and 0·23 sec. losing to the last observation only.

The comparison of " S.C." with the mean time chronometers was carried out by the help of the coincidence apparatus. At the coincidence between the beat of the chronometer and that of the coincidence apparatus, the corresponding times of " S.C." and " E " were simply noted.

Pendulum Observations, July 12th to 16th, 1912.

Determination of Flexure Correction.

The observations for flexure were made $3\frac{1}{2}$ times and gave the following results :—

	Nos. 5 and 7.		No. 21.
	$25 \cdot 1 \times 10^{-7}$ sec.		
	24·4		$35 \cdot 0 \times 10^{-7}$ sec.
	22·9		32·0
	25·1		33·1
mean	$24 \cdot 4 \pm 0 \cdot 35$	mean	$33 \cdot 3 \pm 0 \cdot 59$

The Barometer Correction was calculated from the corrected readings of No. 1157.

For the humidity correction, a pair of wet and dry bulb thermometers were used.

Temperature Correction.—Thermometer No. 41203 was used in the dummy pendulum and the appropriate corrections applied.

In this and the succeeding series, 20 coincidences were observed each time instead of the usual 10.

The analysis of the results is given in Table XXXIII, and in Table XXXIV are summarized the results by the individual pendulums.

Table XXXIV.

	No. 5.	No. 7.	No. 21.	Mean.
	0·5078981 sec.	0·5078726 sec.	0·5093020 sec.	0·5083576 sec.
	990 ,,	723 ,,	012 ,,	575 ,,
	980 ,,	709 ,,	012 ,,	567 ,,
	966 ,,	717 ,,	005 ,,	563 ,,
	951 ,,	716 ,,	991 ,,	553 ,,
	968 ,,	717 ,,	008 ,,	564 ,,
	973 ,,	712 ,,	013 ,,	566 ,,
Mean...	0·5078973 sec.	0·5078717 sec.	0·5093009 sec.	0·5083566 sec.

In Table XXXV below, are set out the differences and their squares for the individual pendulums.

Table XXXV.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	8×10^{-7} sec.	64	9×10^{-7} sec.	81	11×10^{-7} sec.	121	10×10^{-7} sec.	100
	17	289	6	36	3	9	9	81
	7	49	8	64	3	9	4	16
	7	49	0	0	4	16	3	9
	22	484	1	1	18	324	13	169
	5	25	0	0	1	1	2	4
	0	0	5	25	4	16	0	0
Σ (vv) ...		960		207		496		379

The probable errors of the individual results are therefore—

$$e_5 = 8\cdot4\times10^{-7} \text{ sec.}$$
$$e_7 = 3\cdot9$$
$$e_{21} = 6\cdot0$$
$$e_m = 5\cdot3\times10^{-7} \text{ sec.}$$

and

$$p_5 = 2\cdot7\times10^{-7} \text{ sec.}$$
$$p_7 = 1\cdot5$$
$$p_{21} = 2\cdot3$$
$$p_m = 2\cdot0\times10^{-7} \text{ sec.}$$

The values of e_x and p_x above are somewhat better than those deduced from the observations of Series "B," and it is clear that a certain gain in accuracy has been achieved.

TABLE XXXVI.

	M_p—5.	M_p—7.	21—M_p.
	4595×10^{-7} sec.	4850×10^{-7} sec.	9444×10^{-7} sec.
	85	52	37
	87	58	45
	97	46	42
	4602	37	38
	4596	47	44
	93	54	47
Mean...	4594	4849	9442

TABLE XXXVII.

	M_p—5.		M_p—7.		21—M_p.	
v (vv) ...	1×10^{-7} sec.	1	1×10^{-7} sec.	1	2×10^{-7} sec.	4
	9	81	3	9	5	25
	7	49	9	81	3	9
	3	9	3	9	0	0
	8	64	12	144	4	16
	2	4	2	4	2	4
	1	1	5	25	5	25
Σ (vv) ...		209		273		83

From Tables XXXVI and XXXVII, we see that the probable error of a single difference—

$$\begin{aligned} M_p—5 &= 3\cdot9\times10^{-7} \text{ sec.} \\ M_p—7 &= 4\cdot5 \\ 21—M_p &= 2\cdot5 \end{aligned}$$

Mean value $3\cdot6\times10^{-7}$ sec.

A comparison of these figures with the corresponding one of series B, shows only a very slight gain in the accuracy of observation. At the same time, a comparison with the observations of Potsdam I is not at all unfavourable, and such difference as is indicated, may readily be referred to the still unsatisfactory action of the spring in the coincidence apparatus or the contact in the clock. In spite of this approximate agreement, the value of e_m is $5\cdot3\times10^{-7}$ sec. compared with $1\cdot9\times10^{-7}$ sec. for Potsdam I, and this is clear proof that the errors here are instrumental rather than observational.

CAPE EVANS, SERIES " D."

(AUG. 13TH TO 17TH.)

Little comment is required on this last series. The actual observations were made in precisely the same manner as those of July 12th to 16th (Series " C ").

The observations for time were, however, defective in this respect, that during the whole of the series a blizzard was raging, and this prevented the possibility of getting intermediate determinations of time.

In applying the time correction, considerable trouble was experienced as a result of the fact that, between the two sets of star sights, the rate of " S.C." experienced a change of considerable magnitude, due presumably to the winding of the clock. It has therefore been thought advisable to calculate the rate of " S.C." on each day from comparisons with " E," on the assumption that the rate of " E " remained constant between the two sets of time sights.

The results of intercomparison of " S.C." and " E " gave the following results :—

	" S.C."—" E."
Aug. 12th, 9 p.m., to 13th, 9 p.m.	236·59 secs. per day.
,, 13th ,, 14th ,, ...	236·41 ,, ,,
,, 14th ,, 15th ,, ...	236·31 ,, ,,
,, 15th ,, 16th ,, ...	236·42 ,, ,,
,, 16th ,, 17th ,, ...	235·64 ,, ,,
,, 17th ,, 18th, a.m.	235·69 ,, ,,

The following differences per day have therefore been assumed for " S.C."—" E " at the times of pendulum observation :—

Aug. 13th, a.m. observations,	236·58 secs.	Aug. 16th, p.m. observations,	236·03 secs.
,, 13th, p.m. ,,	236·50 ,,	,, 17th, a.m. ,,	235·64 ,,
,, 14th, a.m. ,,	236·41 ,,	,, 17th, p.m. ,,	235·69 ,,
,, 14th, p.m. ,,	236·36 ,,		
,, 15th, a.m. ,,	236·31 ,,		
,, 15th, p.m. ,,	236·36 ,,		
,, 16th, a.m. ,,	236·42 ,,		

From the actual sights, we obtain a mean value for sidereal time —" E "=236·46 secs. daily, from which we are able to deduce the following results:—

					Correction to time of swing.
1st set of observations, " S.C."	gaining	0·13	sec.	daily	— 8×10^{-7} sec.
2nd ,, ,,	,,	0·04	,,	,,	— 2
3rd ,, ,,	losing	0·05	,,	,,	+ 3
4th ,, ,,	,,	0·10	,,	,,	+ 6
5th ,, ,,	,,	0·15	,,	,,	+ 9
6th ,, ,,	,,	0·10	,,	,,	+ 6
7th ,, ,,	,,	0·04	,,	,,	+ 2
8th ,, ,,	,,	0·43	,,	,,	+25
9th ,, ,,	,,	0·82	,,	,,	+48
10th ,, ,,	,,	0·77	,,	,,	+45

The actual observations for time are set down in Table XXXVIII.

TABLE XXXVIII.

Date. 1912.	*.	A.	Az.	t_1.	t.	α.	dt.	Means. Sec.
Aug. 12th	ϕ-Sag.	1·086	7·68	41·35	33·67	12·79	39·12	
,,	σ-Sag.	1·084	7·65	80·18	72·53	51·81	39·28	39·13 ± 0·08
,,	ζ-Sag.	1·102	7·78	93·01	85·23	64·23	39·00	
,,	τ-Sag.	1·092	7·70	58·81	51·11	30·22	39·11	
Aug. 12th	ϕ-Sag.	1·086	7·68	40·35	32·67	12·75	40·08	
,,	σ-Sag.	1·084	7·65	79·19	71·54	51·77	40·23	
,,	ζ-Sag.	1·102	7·78	91·18	83·40	64·20	40·80	40·48 ± 0·25
,,	τ-Sag.	1·092	7·70	57·07	49·37	30·19	40·82	

Date.	L.M.T.	dt.	Interval.	Loss.	Mean Daily Rate.
Aug. 12th ...	9.30 a.m.	39·13 sec.	5·98 days.	1·35 sec.	0·23 sec. losing.
,, 18th ...	9.30 a.m.	40·48 ,,			

From the Table, it will be seen that the mean azimuth correction is —7·70 sec. on each day, so that no error is introduced on account of uncertainty in the value of this constant.

The correction for flexure was determined twice and gave the following values :—

	Nos. 5 and 7.	No. 21.
	$24 \cdot 2 \times 10^{-7}$ sec.	$33 \cdot 1 \times 10^{-7}$ sec.
	25·1	33·0
Mean	25	33

The analysis of the results is put down in Table XXXIX and redistributed in Table XL.

TABLE XXXIX.

	No. 5.	No. 7.	No. 21.	Mean.
	0·5078956 sec.	0·5078716 sec.	0·5092995 sec.	0·5083556 sec.
	984 ,,	720 ,,	979 ,,	561 ,,
	979 ,,	713 ,,	997 ,,	563 ,,
	991 ,,	723 ,,	3 035 ,,	583 ,,
	982 ,,	720 ,,	006 ,,	569 ,,
	987 ,,	691 ,,	2 987 ,,	555 ,,
	948 ,,	704 ,,	3 012 ,,	555 ,,
	980 ,,	697 ,,	023 ,,	567 ,,
	945 ,,	688 ,,	000 ,,	544 ,,
	979 ,,	720 ,,	020 ,,	573 ,,
Mean	0·5078973 sec.	0·5078709 sec.	0·5093005 sec.	0·5083563 sec.

TABLE XL.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	17×10^{-7} sec.	289	7×10^{-7} sec.	49	10×10^{-7} sec.	100	7×10^{-7} sec.	49
	11	121	11	121	26	676	2	4
	6	36	4	16	8	64	0	0
	18	324	14	196	30	900	20	400
	9	81	11	121	1	1	6	36
	14	196	18	324	18	324	8	64
	25	625	5	25	7	49	8	64
	7	49	12	144	18	324	4	16
	28	784	21	441	5	25	19	361
	6	36	11	121	15	225	10	100
Σ (vv) ...		2511		1558		2688		1094

From Table XL we obtain—

$e_5 = 11 \cdot 2 \times 10^{-7}$ sec. $\qquad p_5 = 3 \cdot 5 \times 10^{-7}$ sec.

$e_7 = 8 \cdot 8 \qquad p_7 = 2 \cdot 8$

$e_{21} = 11 \cdot 5 \qquad p_{21} = 3 \cdot 6$

$e_m = 7 \cdot 4 \qquad p_m = 2 \cdot 3$

These values of e_r are therefore slightly worse than those of the preceding set, and still some three times as bad as those of Potsdam I. They seem, however, to be somewhat more free from systematic errors.

For the differences of each pendulum from the mean, Tables XLI and XLII are, as usual, formed below :—

TABLE XLI.

	M_p-5.	M_p-7.	$21-M_p$.
	4600×10^{-7} sec.	4840×10^{-7} sec.	9439×10^{-7} sec.
	4577	41	18
	84	50	34
	92	60	52
	87	49	37
	65	64	32
	4607	51	57
	4587	70	56
	99	56	56
	94	53	47
Mean	4589	4853	9443

TABLE XLII.

	M_p-5.		M_p-7.		$21-M_p$.	
v (vv) ...	11×10^{-7} sec.	121	13×10^{-7} sec.	169	4×10^{-7} sec.	16
	12	144	12	144	25	625
	5	25	3	9	9	81
	3	9	7	49	9	81
	2	4	4	16	6	36
	24	576	11	121	11	121
	18	324	2	4	14	196
	2	4	17	289	13	169
	10	100	3	9	13	169
	5	25	0	0	4	16
Σ (vv) ...		1332		810		1510

From these we obtain :—

for the difference $M_p-5 \quad = 8\cdot1\times10^{-7}$ sec.

,, $\qquad M_p-7 \quad = 6\cdot3\times10^{-7}$,, $\qquad$ mean $7\cdot7\times10^{-7}$ sec.

,, $\qquad 21-M_p = 8\cdot6\times10^{-7}$,,

The mean value $7\cdot7\times10^{-7}$ sec. is more than twice as great as that calculated from the observations of series "C"—a result which is probably to be referred to the shaking of the whole hut by the force of the blizzard wind.

OBSERVATIONS AT CHRISTCHURCH, 1913.

Latitude = 43·31′ 50″ S. *Longitude* = 172° 38′ 09″ E.

This set of observations in 1913 was undertaken largely in the hope of getting a more accurate value for " g " at this spot. Profiting by the experience of the former visit, the observations were this time made in the " magnetic variation " house in order to do away with temperature troubles. This meant that the iron in the pendulum apparatus was bound to disturb the action of the magnetometers. Notwithstanding this, Mr. H. F. Skey, Director of the Observatory, not only gave permission, but also actively helped in its installation in the magnetic variation house.

In order that the magnetic work should not be disturbed too much, it was decided to dispense with a pillar altogether and to place the stand directly on the concrete floor. The stand therefore rested on the three base plates for the levelling screws and these were simply cemented to the floor with plaster of Paris. The clock " S.C." hung on one of the concrete walls and was firmly wedged in place. Portable field telephones permitted the proper numbering of the seconds to the observer at the transit instrument some 60 yards away, in a manner exactly analogous to that used at Winter Quarters. All current for light, telephones, etc., was furnished from a set of portable accumulators. A small relay was used on a separate lead to the transit instrument, in order that the ticks of the clock should always be audible at the other end of the telephone.

Instead of the transit instrument used in the previous observations, a slightly smaller one was kindly lent by Mr. Skey. This was set up on the concrete pillar which had been erected by Mr. Skey for the first observations in 1910. A new fixed mark was made in the form of a small electric light screwed to a heavy wooden post well buried in the ground about 150 yards from the pillar.

In addition to the meridian transit observations made at Christchurch, Mr. C. E. Adams undertook similar observations at the Hector Observatory, Wellington, in order to guard against the possibility of cloudy weather. By the kindness of the telegraph service, a through line was provided to Wellington for a short time twice a day, and the beats of " S.C." were recorded on a chronograph at Wellington.

As an additional precaution, " S.C." was rated several times daily against the portable chronometer " E " which rendered such satisfactory service at Cape Evans, and the portable observatory chronometer.

The observations for time taken at Wellington by Mr. Adams are not given in full, but stars were observed on the evenings of Feb. 28th, March 3rd and March 5th, the probable errors on these days being ±0·03, 0·04 and 0·03 sec., respectively. The deduced daily rate of the Observatory standard was 0·77 sec. losing for the first period, and 0·73 sec. losing for the second period.

Through the medium of the tape and printing chronographs at Wellington, " S.C."

was compared with the Wellington Observatory standard on Feb. 28th, and on March 1st and 3rd. From these comparisons, "S.C." is found to have had the following losing rates:—

Feb. 28th–March 1st	2·82 sec. daily.
March 1st–March 3rd	2·45 ,, ,,

The Christchurch time observations gave the following losing rates:—

Feb. 28th–March 1st	2·78 sec. daily.
March 1st–March 2nd	2·45 ,, ,,
March 2nd–March 3rd	2·50 ,, ,,

The agreement is well within the limits of probable error of the latter observations.

From comparison of "S.C." with the two portable chronometers, there is evidence that the latter two chronometers were keeping a consistent rate, but that "S.C.'s" rate was very irregular on the 28th and on the morning of the 1st March, no doubt owing to the fact that "S.C." was wound just before the commencement of the series of observations. For this reason, it has been deemed advisable to discard the first pair of observations entirely and to apply the rate of 2·45 sec. losing daily to the four last observations.

The value for flexure was observed four times for pendulum No. 21, and three times for Nos. 5 and 7, and is given below.

	Nos. 5 and 7.	No. 21.
Feb. 28th	$33 \cdot 9 \times 10^{-7}$ sec.	$62 \cdot 8 \times 10^{-7}$ sec.
,, ...	—	43
Mar. 5th	51·7	45·7
,, ...	48·7	46·8
Adopted values	50	46

The values obtained were very variable, and it was decided to adopt the values of March 5th and to neglect the observations made before the series commenced. This point should be borne in mind when discussing the cause of the anomalous results obtained at Christchurch.

The temperature was measured by thermometer No. 29110, in the dummy pendulum resting on the cork base. The temperature was very steady throughout the observations, remaining constant between 15°·33 C. and 15°·89 C., with a maximum variation at the rate of 0°·06 per hour.

The same barometer, read at least once every 40 minutes during the period of observation, was used as in the 1910 observations at Christchurch.

Humidity corrections were applied from the readings of the pair of wet and dry bulb thermometers.

The results of the pendulum observations are given in Tables XLIII and XLIV.

TABLE XLIV.

No. 5.	No. 7.	No. 21.	Mean.
0·5085229 sec.	0·5084990 sec.	0·5099389 sec.	0·5089869 sec.
307 ,,	5077 ,,	463 ,,	949 ,,
269 ,,	0·5085058 ,,	403 ,,	910 ,,
259 ,,	048 ,,	428 ,,	912 ,,
255 ,,	054 ,,	406 ,,	905 ,,
253 ,,	046 ,,	383 ,,	894 ,,
Mean of last four— 0·5085259 sec.	0·5085052 sec.	0·5099405 sec.	0·5089905 sec.

v.	$(vv.)$	v.	$(vv.)$	v.	$(vv.)$	v.	$(vv.)$
$+10\times10^{-7}$ sec.	100	$+6\times10^{-7}$ sec.	36	-2×10^{-7} sec.	4	$+5\times10^{-7}$ sec.	25
0	0	-4	16	$+23$	529	$+7$	49
-4	16	$+2$	4	$+1$	1	0	0
-6	36	-6	36	-22	484	-11	121
$\Sigma\,(vv)$	152		92		1018		195

From these, we find the probable error of a single value to be :—

$$e_5 = 4\cdot8\times10^{-7} \text{ sec.}$$
$$e_7 = 3\cdot7$$
$$e_{21} = 12\cdot4$$
$$e_m = 5\cdot4$$

The probable errors of the mean result become :—

$$p_5 = 2\cdot4\times10^{-7} \text{ sec.}$$
$$p_7 = 1\cdot8$$
$$p_{21} = 6\cdot2$$
$$p_m = 2\cdot7$$

As in previous cases, Table XLV is formed in order to examine the observational accuracy independent of errors due to variations in clock rate from one set of observations to another.

TABLE XLV.

	M_p-5.	M_p-7.	$21-M_p$.
	4640×10^{-7} sec.	4879×10^{-7} sec.	9520×10^{-7} sec.
	42	72	9514
	41	52	9493
	53	64	9516
	50	51	9501
	41	48	9489
Means	4644	4861	9506

v.	$(vv.)$	v.	$(vv.)$	v.	$(vv.)$
-4×10^{-7} sec.	16	$+18\times10^{-7}$ sec.	321	$+14\times10^{-7}$ sec.	196
-2	4	$+11$	121	$+8$	64
-3	9	-9	81	-13	169
$+9$	81	$+3$	9	$+10$	100
$+6$	36	-10	100	-5	25
-3	9	-13	169	-17	289
$\Sigma (vv)$	155		804		843

From this, we get the probable errors of a single pendulum comparison :—

$M_p - 5 \;= 3\cdot8\times10^{-7}$ sec.
$M_p - 7 \;= 8\cdot6$
$21 - M_p = 8\cdot8$, the mean value of which is $7\cdot1\times10^{-7}$ sec.

The agreement between this figure and the mean value of e_5, e_7, and e_{21} may be taken as an indication that the chronometer "S.C." was behaving satisfactorily during March 2nd and 3rd.

A comparison of the mean values of this series with the 1910 series shows, however, a lamentable lack of agreement. Thus, the values in the two years for the three pendulums were, respectively :—

	No. 5.	No. 7.	No. 21.	Mean.
1910 ...	(0·5085396) sec.	0·5085121 sec.	0·5099429 sec.	0·5089982 sec.
1913 ...	(259) ,,	052 ,,	405 ,,	905 ,,

Except in the case of pendulum No. 21, the discrepancies are quite outside the limits of probable error, even allowing for the very unsatisfactory observations of 1910.

The clue to the discrepancy is found in Tables XLVI and XLVII, the values for the differences between individual pendulums and the mean being:—

Table XLVI.

	$M_p - 5$.	$M_p - 7$.	$21 - M_p$.
Christchurch, 1910 ...	4586×10^{-7} sec.	4862×10^{-7} sec.	9446×10^{-7} sec.
,, 1913 ...	4644	4861	9506
Potsdam (mean) ...	4605	4856	9460

More information is obtained by the differences between individual pendulums, which give the values:—

Table XLVII.

	5—7.	21—7.	21—5.
Christchurch, 1910...	$(275) \times 10^{-7}$ sec.	14308×10^{-7} sec.	$(14033) \times 10^{-7}$ sec.
,, 1913...	206	14353	14146
Potsdam (mean) ...	252	14316	14066

Clearly, pendulum No. 5 was reading about 25×10^{-7} sec. too high in 1910, while Nos. 7 and 21 were nearly normal. Equally certainly, no two pendulums were giving consistent readings in 1913, so that the *best* one can assume is that No. 21 was giving the correct times of swing in that year.

The cause of these abnormal, but consistent, errors is difficult to trace, and one can only suggest that, in the year 1913, it was associated with the unsatisfactory observations for flexure. Possibly, a change of level took place before the observations commenced, but no mention has been found in the records of anything bearing on this point. It is possible, but difficult to believe, that a slight earthquake may be the cause of the inconsistencies, and it seems more reasonable to assume that they are due to a faulty setting up of the apparatus.

The misfortunes of this Expedition at Christchurch are paralleled by those of the previous Scott Expedition, the values for "g" then obtained also varying greatly from one pendulum to another.

The only safe procedure would be to neglect both sets of observations, but it seems likely that a less inaccurate value for "g" at Christchurch is given by these observations than by those of the "Discovery" Expedition. This point is discussed later in deriving the most probable values for "g" at the various field stations.

In these observations, the arrangement which had been designed to take the place of the coincidence apparatus was used for the first time. The arrangement was chosen with the object of having no moving parts to get out of order, and choice fell on a combination of induction coil and vacuum tube. With this arrangement, the hammer of the mechanical " break " for the induction coil is screwed up tight so that it cannot move. If now the vacuum tube is joined up to the secondary of the coil, and a suitable number of accumulators with appropriate resistance, capacity, and inductance to the primary coil, every " break " in the primary current will cause a flash in the vacuum tube, while the " make " shows no visible effect. With a properly designed coil, a flash is given for a very low primary current and this is of advantage in that it reduces the amount of current through, and of sparking at, the clock contacts.

In these observations a small vacuum tube about 8 inches long filled with helium was used as the source of light and gave a fine bright yellow light at every break.*

To show the accuracy of the observations with this form of apparatus, Table XLVIII below is taken from the Christchurch 1913 observations. For comparison, two similar observations of the coincidence interval, one from Potsdam I, and the other from Cape Evans " C," are given in the same Table.

TABLE XLVIII.

Potsdam I.			Cape Evans C.			Christchurch, 1913.		
Min.	Sec.		Min.	Sec.		Min.	Sec.	
29	15·0	14·7	27	09·4	09·8	27	00·3	00·4
	14·6	14·7		09·2	09·6		00·3	00·5
	14·7	14·8		09·1	09·7		00·4	00·5
	14·8	15·0		09·4	10·2		00·3	00·5
	14·9	15·1		09·4	10·0		00·3	00·5
Mean	14·83							
				09·6	09·9		00·3	00·4
				09·3	09·6		00·3	00·6
				09·3	10·2		00·4	00·4
				09·4	10·1		00·5	00·5
				09·4	09·7		00·4	00·5
			Mean	09·615		Mean	00·35	

The consistency of the results at Christchurch with this arrangement could hardly be bettered, but an extended trial would be necessary before a statement of the relative accuracy of the two methods could be made.

* Note added, June, 1914.—This arrangement, it is found, was used long ago by Dr. Horton in his researches on the elasticity of quartz fibres at the Cavendish Laboratory. The technique is much improved by the use of vacuum tubes filled with neon, as this gives a red spark of much greater brightness for the same current density. A further improvement is introduced by the use of a very small vacuum tube only $1\frac{1}{2}$ inches long and with a constriction only $\frac{1}{8}$ inch in length. Since our return, a small coil has been made by Cox to my specifications. This works with a single accumulator and gives a fine bright spark with only 0·03 amp. in the primary circuit. No external capacity is needed with this instrument and the whole apparatus is exceedingly light and very simply set up. The set built by Cox has been sent to the Indian Survey for trial at their field stations.

OBSERVATIONS AT WELLINGTON.

March, 1913.

Hector Observatory. *Latitude*, 41° 17′ 03″9 S. *Longitude*, 174° 46′ 03″4 E.

Height above mean sea-level, 401·5 *feet*.

For the Observations at Wellington, Mr. C. E. Adams, the Government Astronomer, kindly lent the use of an underground chamber below the Observatory, which had once belonged to the old Fort in whose place the Hector Observatory now stands. With the help of the Public Works Department, the alterations deemed necessary were made. These consisted in the erection of a solid pillar of brick faced with concrete. This was of 66 cms. side at the base, at the top of 47 cms. side, and of total height 51 cms. Rigidly cemented to the top was a marble slab 2 inches thick and 66 cms. square. In addition, a considerable amount of wiring was done by the Department, in order that electric light might be used for illumination purposes, so as to keep the temperature as constant as possible. Other wires were also laid to enable " S.C." to be compared by chronograph with the Observatory standard.

The pillar is 20·5 links south and 79·1 links west of the transit instrument.

The pendulum stand stood on the pillar in a small room by itself, and was observed from outside through a glass door with a small section of the glass removed.

The clock " S.C." hung from a heavy wooden beam wedged between two parallel walls, and was fastened below to a similar beam of wood.

In the same passage as the clock was set up the flash apparatus, at a distance of 360 cms. from the pendulum mirrors. For making the flash the same arrangement was used as in the Christchurch observations—the same helium tube and a large Cox's coil lent by Professor Laby. Professor Laby, in addition, supplied a number of storage cells and other gear, and also gave much valuable assistance.

The pendulum clock " S.C." was again used for the coincidences, and was compared with the Observatory standard before and after each set of observations by means of the Gautier printing chronograph belonging to the Observatory.

Mr. Adams made the necessary time observations for rate of the standard, and his covering report is given herewith :—

> " Owing to the prevalence of wet and cloudy weather, no attempt could be made to follow any systematic programme in the selection of time stars, but every opportunity was taken to observe on every possible occasion, and all stars observed have been used in the determination of the clock error.
>
> " In the least square solution, weights depending on the star's declination have

been applied in accordance with the experience of the United States Coast and Geodetic Survey (see Appendix No. 7, Report for 1897–98, page 291).

"The transit instrument used was of 3-inch aperture and 36-inch focal length, with central illumination from the front of the objective, as described in the Monthly Notices of the Royal Astronomical Society, Vol. 68, page 181, and the method of observation was to reverse the instrument on every star. By this means no correction for collimation was required.

"For the first series of observations, the transit micrometer and a tape chronograph were used, while, for the second series, the hand key and a Gautier printing chronograph, made by the Société Génevoise, were used.

"Tests for personal equation were made on a transit of the sun on March 20th, when Mr. Wright observed the first seven wires and Mr. Adams observed the remaining eight wires: the instrument was then reversed and each observer completed his observations on the wires previously used, the result being that Mr. Wright observed 0·23 seconds later than Mr. Adams.

"A complete example of the least square reduction of the observations taken on March 5th is forwarded herewith. As will be seen from the schedule, column 7 gives the right ascension—clock time of transit, corrected for level, clock rate, diurnal aberration and half-width of contact strip of the transit micrometer. Column 10 gives A, the azimuth correction. The headings of the other columns explain their formation.

"The clock correction is $\Delta T_0 = \Delta T + \delta T$, where

$$\Delta T = \text{mean of } \alpha - t_1,$$
$$d = \alpha - t_1 - \Delta T,$$

the least square calculation gives a, the azimuth deviation from the meridian in seconds of time, and δT the correction to ΔT in seconds of time.

"The right ascensions have been taken from the 'Nautical Almanac.'"

Table XLIX.

March 17th, 1913.

Star.	Decl.	Clock Time of Transit.	Corrections.			Seconds of Corrected Clock Time of Transit.*	R.A.	R.A.-Clock.	Azimuth Correction.	Clock Apparently Slow.	V.	Method of Observation.	Observer.
			Level.	Rate.	Di. Aber.								
	° ′	h. m. s.	s.	s.	s.	s.	h. m. s.	s.	s.	s.*	s.		
ν-Orionis ...	N.14 47	6 2 32·105	0·114	—0·031	—0·016	32·17	6 2 37·07	4·90	—0·04	+4·94	+0·07	Hand key and printing chronograph.	Mr. C. E. Adams.
η-Geminorum	N.22 32	6 9 33·465	0·094	—0·028	—0·017	33·51	6 9 38·46	4·95	—0·04	4·99	+0·12		
ν-Argus ...	S.43 7	6 35 1·445	0·270	—0·016	—0·022	1·68	6 35 6·68	5·68	—0·00	5·00	+0·13		
α-Canis Majoris	S.16 36	6 41 14·650	0·187	—0·014	—0·016	14·81	6 41 19·41	4·60	—0·02	4·62	—0·25		
α-Pictoris ...	S.61 51	6 47 13·705	0·391	—0·011	—0·033	14·05	6 47 18·61	4·56	+0·03	4·53	—0·34		
ε-Canis Majoris	S.28 51	6 55 8·160	0·220	—0·007	—0·018	8·36	6 55 13·20	4·84	—0·01	4·85	—0·02		
γ-Canis Majoris	S.15 30	6 59 45·295	0·184	—0·005	—0·016	45·46	6 59 50·26	4·80	—0·02	4·82	—0·05		
δ-Canis Majoris	S.26 15	7 4 47·045	0·212	—0·002	—0·018	47·24	7 4 52·04	4·80	—0·01	4·81	—0·06		
δ-Volantis ...	S.67 48	7 16 48·080	0·466	—0·003	0·042	48·51	7 16 53·83	5·32	+0·05	5·27	+0·40		
σ-Leonis ...	N. 9 48	10 28 10·815	0·126	—0·092	0·016	11·02	10 28 15·82	4·80	—0·04	4·84	—0·03		
								(10)48·57		(10)48·67			
								4·86		4·87	0·04		

δT = —0·01 sec. = —0·05 sec.

* Corrected for level, clock-rate and diurnal aberration.

E

TABLE XLIX. (continued).

March 18th, 1913.

Star.	Decl.	Clock Time of Transit.	Corrections. Level.	Corrections. Rate.	Corrections. Di. Aber.	Seconds of Corrected Clock Time of Transit.*	R.A.	R.A.-Clock.	Azimuth Correction.	Clock Apparently Slow.	V.	Method of Observation.	Observer.
	° ′	h. m. s.	s.	s.	s.	s.	h. m. s.	s.	s.	s.	s.		
π-Leonis ...	N. 8 28	9 55 32·870	0·119	0·006	0·016	32·97	9 55 38·84	5·87	0·21	5·66	0·03	Hand key and printing chronograph.	Mr. C. E. Adams.
α-Leonis ...	N.12 24	10 3 40·380	0·110	0·001	0·016	40·47	10 3 46·32	5·85	0·22	5·63	0·00		
q-Velorum ...	S.41 41	10 11 00·630	0·240	0·003	0·021	00·86	10 11 6·34	5·48	0·00	5·48	0·15		
q-Carinæ ...	S.60 54	10 14 6·365	0·352	0·005	0·032	6·69	10 14 12·25	5·56	0·19	5·75	0·12		
								(4) 2·76		(4) 2·52			
								5·69		5·63	0·04		

$\delta T = -0{\cdot}07$ sec. $\alpha = +0{\cdot}27$ sec.

* Corrected for level, clock-rate and diurnal aberration.

TABLE XLIX. (continued).

March 19th, 1913.

Star.	Decl.	Clock Time of Transit.	Corrections.			Seconds of Corrected Clock Time of Transit.*	R.A.	R.A.-Clock.	Azimuth Correction.	Clock Apparently Slow.	V.	Method of Observation.	Observer.
			Level.	Rate.	Di. Aber.								
	° ′	h. m. s.	s.	s.	s.	s.	h. m. s.	s.	s.	s.	s.		
θ-Argus ...	S. 63 56	10 39 46·060 — ·230	0·342	—0·029	—0·036	46·11	10 39 52·84	6·73	—0·12	6·85	—0·05	Hand key and printing chronograph.	Mr. C. S. Wright.
δ-Crateris ...	S. 14 18	11 14 54·130 — ·230	0·150	—0·002	—0·016	54·03	11 15 1·08	7·05	0·07	6·98	0·08		
λ-Centauri ...	S. 62 32	11 31 40·770 — ·230	0·329	0·011	—0·034	40·85	11 31 47·65	6·80	0·11	6·91	0·01		
β-Leonis ...	N. 15 4	11 44 32·640 — ·230	0·094	0·020	—0·016	32·51	11 44 39·47	6·96	0·12	6·84	0·06		
		—0·230 deducted to reduce to Mr. C. E. Adams.						(4) 27·54 6·89		(4) 3·58 6·90	0·02		

$\delta T = +0{\cdot}01$ sec. $\alpha = +0{\cdot}14$ sec.

* Corrected for level, clock-rate, diurnal aberration and personal equation between Mr. C. E. Adams and Mr. C. S. Wright :—to reduce observations by Mr. Wright to observations by Mr. Adams deduct 0·230 second.

TABLE XLIX. (continued).

March 20th, 1913.

Star.	Decl.	Clock Time of Transit.	Corrections.			Seconds of Corrected Clock Time of Transit.*	R.A.	R.A.-Clock.	Azimuth Correc-tion.	Clock Apparent-ly Slow.	V.	Method of Observa-tion.	Ob-server.
			Level.	Rate.	Di. Aber.								
	° ′	h. m. s.	s.	s.	s.	s.	h. m. s.	s.	s.	s.	s.		
β-Orionis ...	S. 8 18	5 10 13·970	0·176	0·015	0·016	14·12	5 10 21·70	7·58	0·11	7·47	0·00	Hand key and printing chrono-graph.	Mr. C. E. Adams.
γ-Orionis ...	N. 6 16	5 20 20·610	0·141	0·007	0·016	20·73	5 20 28·27	7·54	0·15	7·39	0·08		
ϵ-Orionis ...	S. 1 59	5 36 14·680	0·161	0·007	0·016	14·83	5 36 22·61	7·78	0·13	7·65	0·18		
κ-Orionis ...	S. 9 42	5 43 30·630	0·180	0·013	0·016	30·81	5 43 38·30	7·49	0·11	7·38	0·09		
								(4) 2·39		(4) 1·89			
								7·60		7·47	0·04		

$\delta T = -0{\cdot}13$ sec. $\alpha = +0{\cdot}21$ sec.

* Corrected for level, clock-rate and diurnal aberration.

TABLE XLIX. (continued).

SUMMARY.

Date.	Epoch.		Clock Correction.		Clock Rate.		Observer.
					Sidereal Day.	Sidereal Hour.	
	h. m.	h.	s.	s.	s.	s.	
March 17th, 1913	7 10		4·87 ± 0·04				C. E. Adams.
		26·93		+0·76	+0·68	+0·03	
,, 18th ,, ...	10 6		5·63 ± 0·04				C. E. Adams.
		25·20		+1·28	+1·22	+0·05	
,, 19th ,, ...	11 18		6·91 ± 0·02				C. S. Wright.
		18·17		+0·56	+0·74	+0·03	
,, 20th ,, ...	5 28		7·47 ± 0·04				C. E. Adams.

Observations on the sun were also made each day, in case the unsettled weather should not permit the use of stars the following night. It has, however, been thought better not to include the sun observations in the actual rate determinations, as a fixed mark is used with these. They, however, give rates not far from those given by the star observations alone.

In consideration of the fact that the comparison of the personal errors of myself and Mr. Adams were made in a totally different manner to that used in the star observations I have thought it wise to neglect the observation by myself on the 19th, and to apply to Observatory clock (1) a uniform rate of $+1 \cdot 02$ sec. from the 18th to the 20th.

In either case, the mean value of the mean pendulum comes out the same, but much more consistent results are obtained if my observation is neglected.

The analysis of the time observations is given in Table L.

Flexure.—The correction for flexure was three times observed and gave the values :—

Nos. 5 and 7.	No. 21.
$19 \cdot 4 \times 10^{-7}$ sec.	$29 \cdot 0 \times 10^{-7}$ sec.
$19 \cdot 9$	$29 \cdot 9$
$21 \cdot 6$	$31 \cdot 2$
$20 \cdot 3 \pm 0 \cdot 4$	$30 \cdot 0 \pm 0 \cdot 4$

The temperature was measured by No. 29110 in the dummy pendulum resting on the cork base. Its error has been taken as $-0° \cdot 07$ C. at the temperature of 15° C. and this correction applied throughout. The temperature in the pendulum room remained very constant with a maximum variation from $14° \cdot 92$ to $15° \cdot 22$ C. The greatest change in temperature during the course of any single swing was $0° \cdot 04$ C. in 35 minutes, so that no correction for lag needs to be applied. The temperature gradient was about $0° \cdot 5$ C. per metre.

The Observatory standard "Barometer, Cooke 2155" was used, and was read once for each set by a single pendulum. The hygrometric correction was applied from the readings of a pair of wet and dry bulb thermometers.

The rate of "S.C." was deduced from comparisons with Observatory standard (1) at the time of star observations, and may be put down in the following manner :—

	"S.C."—(1).	(1)—R.A.		
	sec.	sec.	sec.	sec.
(*a*) Observations 1 and 2	$-11 \cdot 31$	$-0 \cdot 68$	∴ "S.C." losing $11 \cdot 99$	Correction for rate $+706 \times 10^{-7}$
(*b*) ,, 3 and 4	$-10 \cdot 93$	$-1 \cdot 02$	$11 \cdot 95$	$+704$
(*c*) ,, 5 ...	$-11 \cdot 33$	$-1 \cdot 02$	$12 \cdot 35$	$+727$

The results of the pendulum observations are given in Table L and redistributed in Table LI.

TABLE LI.

	No. 5.	No. 7.	No. 21.	Mean.
	0·5085960 sec.	0·5085743 sec.	0·5100047 sec.	0·5090583 sec.
	985	726	053	588
	976	723	052	584
	986	744	060	597
	970	717	053	580
Mean ...	0·5085975	0·5085731	0·5100053	0·5090586

	5.		7.		21.		Mean.	
v (vv) ...	15×10^{-7} sec.	225	12×10^{-7} sec.	144	6×10^{-7} sec.	36	3×10^{-7} sec.	9
	10	100	5	25	0	0	2	4
	1	1	8	64	1	1	2	4
	11	121	13	169	7	49	11	121
	5	25	14	196	0	0	6	36
Σ (vv) ...		472		598		86		174

Thus, the probable error of a single result :—

$$e_5 = 7\cdot2\times10^{-7} \text{ sec.}$$
$$e_7 = 8\cdot2$$
$$e_{21} = 3\cdot1$$
$$e_m = 4\cdot4.$$

The probable error of the mean result :—

$$p_5 = 3\cdot2\times10^{-7} \text{ sec.}$$
$$p_7 = 3\cdot7$$
$$p_{21} = 1\cdot4$$
$$p_m = 2\cdot0.$$

Tables LII and LIII are also formed in order to get an estimate of the accuracy of the comparison between clock and pendulum.

TABLE LII.

	M_p-5.	M_p-7.	$21-M_p$.
	4623×10^{-7} sec.	4840×10^{-7} sec.	9464×10^{-7} sec.
	03	62	65
	08	61	66
	11	53	63
	10	63	73
Mean ...	4611	4856	9466

TABLE LIII.

	M_p-5.		M_p-7.		$21-M_p$.	
$v\ (vv)$	12×10^{-7} sec.	144	16×10^{-7} sec.	256	2×10^{-7} sec.	4
	8	64	6	36	1	1
	3	9	5	25	0	0
	0	0	3	9	3	9
	1	1	7	49	7	49
$\Sigma\ (vv)$...		218		375		63

Giving as the probable error of a single difference :—

$$M_p-5 = 4\cdot9\times10^{-7} \text{ sec.}$$
$$M_p-7 = 6\cdot4 \qquad\qquad \text{Mean } 4\cdot6\times10^{-7} \text{ sec.}$$
$$21-M_p = 2\cdot6$$

MELBOURNE OBSERVATORY.

MARCH 31ST TO APRIL 3RD, 1913.

Latitude, 37° 49′ 53″ S. *Longitude*, 144° 58′·5 E.

Height above mean sea-level, 26·9 *metres*.

By the time the pendulum observations in New Zealand were finished, the "Terra Nova" had already sailed for England, and the apparatus must therefore be carried back with me. As this involved a train journey of a few thousand miles across Canada, it was obvious that the pendulums would be exposed to some danger of being damaged *en route*, and of changing their constants. It therefore seemed necessary to make a series of observations at some spot whose value of "g" was already well determined, in order that the measurements at Cape Evans might still be of value by reference to this secondary base.

Melbourne seemed best suited for the purpose as Hecker and Alessio had only recently redetermined its gravity constant. With the permission of Mr. Baracchi, the same spot in the Astronomical Observatory was used as for the observations by Hecker, and the instruments set up late in March. Unfortunately, for several days it rained almost continuously and no opportunity occurred to get star observations until March 29th.

Observations were started on the morning of March 31st, immediately after re-winding the pendulum clock "S.C.", and were concluded on the evening of April 3rd.

The method of observation was essentially similar to that used at Wellington. The induction coil was furnished this time by the kindness of Professor Lyle. The same helium tube was still in use. The distance from mirrors to scale was 280 cms.

The pressure was read on barometer Hicks 1523 (correction $+0 \cdot 015$ in.), and the correction for aqueous vapour calculated from the readings of a wet and dry bulb thermometer.

The flexure correction was observed three times and gave the following results :—

	Nos. 5 and 7.	No. 21.
March 31st	$26 \cdot 8 \times 10^{-7}$ sec.	$32 \cdot 3 \times 10^{-7}$ sec.
April 1st	$26 \cdot 8$	—
,, 2nd	$27 \cdot 3$	$33 \cdot 9$
,, 3rd	—	$34 \cdot 7$
Mean	$27 \cdot 0\ (\pm 0 \cdot 2) \times 10^{-7}$ sec.	$33 \cdot 6\ (\pm 0 \cdot 8) \times 10^{-7}$ sec.

The temperature was measured, as at Wellington, by thermometer No. 29110, and the same corrections were again applied. The total range of temperature in the dummy pendulum was from $16^\circ \cdot 31$ to $16^\circ \cdot 88$ C. and the maximum change of temperature during the 35 minutes each pendulum was under observation amounted to $0^\circ \cdot 05$ C. in that time.

Time and Rate.—For the observations "S.C." was, as usual, used. It was hung from an iron peg driven into the brick wall and kept rigid by large blocks of wood on each side.

Comparisons were made with the standard clock, "Frodsham 991," before and after each set of swings, by means of a tape chronograph. By taking the mean of about 60 single measurements on the tape, the comparative rates of "S.C." and "Frodsham 991" were deduced from the three-hour intervals over which the observations extended. From these, the comparative daily rate of "S.C." on "Frodsham 991" was calculated, and thus the rate of "S.C." found from the comparison of star observations with No. 991.

The data are put down in Table LIII. It was found that, at the beginning of the observations, the rate of "S.C." was very irregular owing probably to the recent winding of the clock, so that it was thought advisable to discard the first pair of observations, especially as they agreed in no way with the later ones.

The observations for clock rate of "991" were made by Mr. Merfield with the 8-inch meridian circle.

The collimation was determined by two collimators of 6-inch aperture and 78-inch focal length, placed on opposite sides of the rotation axis of the telescope. The level correction was found by coincidence of the middle wire with its reflection in a dish of mercury below the floor. Bessel's method was used by Mr. Merfield for reduction of the observations.

The errors of the instruments were determined by Mr. Merfield for each set of stars. The programme included at least six clock stars and four circumpolar stars. The positions of the clock stars are taken from the "Nautical Almanac."

In Table LIV are found the Instrumental Constants and rate of No. 991.

Table LIV.

Errors and Rates of Transit Clock (Frodsham No. 991) determined from observations made with the 8-inch meridian circle instrument by C. J. Merfield.

Date.*	Time.*	Clock error.	Daily rate at middle of epochs reduced to Bar. 30·00 in.	Daily rate at epoch reduced to Bar. 30·00 in.	Barometer at epoch.	Instrumental Constants.		
						C.	L.	n.
1913.	h. m.	Fast. Sec.	Losing. Sec.	Losing. Sec.	Sec.			
March 29th ...	11 46	56·84		0·94	30·13	0·000	−3·687	(−2·92)
			0·96					
,, 30th ...	9 46	55·91		0·92	30·13	0·000	−3·683	−2·920
			0·86					
,, 31st ...	13 44	54·83		0·86	30·21	0·000	−3·667	−2·619
			0·86					
April 3rd ...	7 8	52·24		0·82	30·18	0·000	−3·652	−2·942

Probable errors of clock corrections :—

March 29th = ±0·018 sec.
,, 30th = ±0·011 ,,
,, 31st = ±0·024 ,,
April 3rd = ±0·009 ,,
,, 4th = ±0·019 ,,

From the observations in Table LIV, the rates of 991 have been formed for the

* Astronomical date, Melbourne mean time.

pressure at which observations of time of swing were made. These are put down below :—

		Rate, "991" losing daily.	("991"— "S.C.") daily	"S.C." losing daily.	Correction.
April 1st, a.m. ...	Barometer 30·223 sec.	0·91 sec.	1·83 sec.	2·74 sec.	$+162\times10^{-7}$ sec.
p.m. ...	30·230 ,,	0·91 ,,	1·95 ,,	2·86 ,,	168
,, 2nd, a.m. ...	30·239 ,,	0·92 ,,	1·81 ,,	2·73 ,,	161
p.m. ...	30·197 ,,	0·90 ,,	1·72 ,,	2·62 ,,	151
,, 3rd, a.m. ...	30·200 ,,	0·90 ,,	1·39 ,,	2·29 ,,	135
p.m. ...	30·174 ,,	0·89 ,,	1·74 ,,	2·63 ,,	155

The analysis of the pendulum observations follows in Tables Nos. LV and LVI.

TABLE LVI.

	No. 5.	No. 7.	No. 21.	Mean.
	0·5086725 sec.	0·5086467 sec.	0·5100783 sec.	0·5091325 sec.
	719	469	780	323
	731	464	781	325
	724	467	796	329
	729	458	781	323
	696	476	797	323
Means	0·5086721	0·5086467	0·5100786	0·5091325

For an estimate of the probable error of the results, Table LVII is next formed.

TABLE LVII.

	No. 5.		No. 7.		No. 21.		Mean.	
v (vv) ...	4×10^{-7} sec.	16	0×10^{-7} sec.	0	3×10^{-7} sec.	9	0×10^{-7} sec.	0
	2	4	2	4	6	36	2	4
	10	100	3	9	5	25	0	0
	3	9	0	0	10	100	4	16
	8	64	9	81	5	25	2	4
	25	625	9	81	11	121	2	4
Σ (vv) ...		818		175		316		28

From which the probable error of a single result—

$e_5 = 8\cdot5\times10^{-7}$ sec.　　$p_5 = 3\cdot5\times10^{-7}$ sec.

$e_7 = 3\cdot9$　　$p_7 = 1\cdot6$

$e_{21} = 5\cdot3$　　$p_{21} = 2\cdot2$

$e_m = 1\cdot6$　　$p_m = 0\cdot65$

If we form the differences of each pendulum from the mean pendulum we get Tables LVIII and LX—

TABLE LVIII.

	$M_p-5.$	$M_p-7.$	$21-M_p.$
	4600×10^{-7} sec.	4858×10^{-7} sec.	9458×10^{-7} sec.
	4604	54	57
	4594	61	56
	4605	62	67
	4594	65	58
	4627	47	74
Mean ...	4604	4857	9462

TABLE LX.

	$M_p-5.$		$M_p-7.$		$21-M_p.$	
$v\ (vv)$	4×10^{-7} sec.	16	1×10^{-7} sec.	1	4×10^{-7} sec.	16
	0	0	3	9	5	25
	10	100	4	16	6	36
	1	1	5	25	5	25
	10	100	8	64	4	16
	23	529	10	100	12	144
$\Sigma\ (vv)$		746		215		262

from which the probable error of a single difference—

$$M_p-5 = 8\cdot1\times10^{-7}\text{ sec.}$$
$$M_p-7 = 4\cdot4 \qquad \text{Mean} = 5\cdot8\times10^{-7}\text{ sec.}$$
$$21-M_p = 4\cdot8$$

INVARIABILITY OF THE PENDULUMS.

In all observations carried out with invariable pendulums, the value of gravity is expressed in terms of the value of some base station (in this case, Potsdam). The value of " g " is deduced from the relative times of swing of the same pendulums at the two places and, for the calculation to hold rigidly, it is necessary for the length of the pendulums to have remained unchanged during this period. If the pendulum has remained unaltered, the initial and final times of swing at the base station will be the same. In general, the two are not identical, and the change experienced by them is some measure of the reliance that can be placed on the value of " g " deduced for the " field " station.

In the present observations, the change experienced by the pendulums during their three years' journey was not excessive—was, in fact, very small considering the dangers to which they had been subject. Table LXI below gives a direct comparison of the initial and final periods of the pendulums at Potsdam.

TABLE LXI.

	No. 5.	No. 7.	No. 21.	Mean.
Potsdam I*	0·5083393 sec.	0·5083137 sec.	0·5097461 sec.	0·5087997 sec.
,, II.	382	137	445	988
Difference...	-11×10^{-7} sec.	No change.	-16×10^{-7} sec.	-9×10^{-7} sec.

There was no change in No. 7, but the changes in No. 5 and No. 21 require further investigation. For this, the differences from the mean pendulum are put down for each station in Table LXII.

TABLE LXII.

	M.	M—5.	M—7.	21—M.
Potsdam I	0·5087997 sec.	4604×10^{-7} sec.	4860×10^{-7} sec.	9464×10^{-7} sec.
Christchurch, 1910	0·5089982 ,,	(4586)	(4861)	(9447)
Cape Evans A ...	(583) ,,	4602	4845	9448
,, B ...	(615) ,,	4606	4847	9452
,, C ...	0·5083566 ,,	4593	4849	9443
,, D ...	0·5083563 ,,	4590	4851	9442
Christchurch, 1913†	0·5089905 ,,	(4646)	(4853)	(9500)
Wellington ...	0·5090586 ,,	4611	4855	9467
Melbourne	0·5091325 ,,	4604	4858	9461
Potsdam II ...	0·5087988 ,,	4606	4851	9457
Potsdam (mean) ...	0·5087992 ,,			

Owing to the difference in period of the various pendulums, the values of M—S in the last three columns should not be the same at each of the different stations. To make them strictly comparable, a correction should be added, which is equal to the difference (M—S) at Potsdam multiplied by the value of $\left(\frac{M_s}{M_p}-1\right)$.‡

* Corrected for temperature lag.

† Last four observations only.

‡ If S_s and S_p represent the time of swing of any pendulum at the field station and at Potsdam respectively, and G_s and G_p the values of "g" at these stations—

$$S_s/S_p = \sqrt{\frac{G}{G_s}} = a,$$

$$\frac{M_s}{M_p} = \sqrt{\frac{G_p}{G_s}} = a,$$

$$\text{and } (S_s-S_p)-(M_s-M_p) = (a \quad 1)\,(S_p-M_p),$$

or correction $= (a-1) \times$ difference from mean pendulum at Potsdam.

M_s and M_p represent here the times of swing of the mean pendulum at the field station and at Potsdam respectively.

At the various stations, the following corrections should therefore be made to the times of swing of the pendulums :—

		No. 5.	No. 7.	No. 21.
Cape Evans	..	-4×10^{-7} sec.	-4×10^{-7} sec.	$+8\times10^{-7}$ sec.
Wellington	..	$+2$	$+2$	-5
Melbourne	..	$+3$	$+3$	-6
Christchurch	..	$+2$	$+2$	-4

By the addition of these figures we obtain the reduced time of swing of each pendulum, and finally the reduced differences in Table LXIII.

Table LXIII.

	M—5.	M—7.	21—M.
Potsdam I	4604×10^{-7} sec.	4860×10^{-7} sec.	9464×10^{-7} sec.
Christchurch, 1910...	(4588)	(4863)	(9451)
Cape Evans A ...	4606	49	56
,, B ...	4610	51	60
,, C ...	4597	53	51
,, D ...	4594	58	50
Christchurch, 1913...	(4648)	(4855)	(9504)
Wellington	4609	53	62
Melbourne	4601	55	55
Potsdam II ...	4606	4851	9457
Mean of field stations	4603	4853	9456

In this Table, indications are seen of a change in the differences for No. 7 and No. 21 which took place before the first field observations at Cape Evans, and of a change in No. 5 operating during Cape Evans B and C. The change, however, is not sufficiently definite in character to lead us to neglect the observations of Potsdam I in arriving at the final values.

A Table (LXIV) showing the differences of the pendulums from one another has also been formed, but this throws little light on the subject beyond confirming the temporary change experienced by No. 5 between the first and second year's observations at Winter Quarters.

Table LXIV.

	5—7.	21—7.	21—5.
Potsdam I, /10 ...	256×10^{-7} sec.	14324×10^{-7} sec.	14068×10^{-7} sec.
Christchurch, /10 ...	(275)	(14314)	(14039)
C. Evans A, /11 ...	243	14305	14062
,, B, /11 ...	241	14311	14070
,, C, /12 ...	256	14304	14048
,, D, /12 ...	264	14308	14044
Christchurch*/13 ...	(207)	(14359)	(14152)
Wellington, /13 ...	244	14315	14071
Melbourne, /13 ...	254	14310	14056
Potsdam II, /13 ...	245	14308	14063

The anomalous differences shown in the Christchurch observations are discussed later.

Temperature Gradient and Variation of Temperature.

It will be remembered that the method of temperature observation was not identical throughout. With the apparatus, was provided a thermometer contained in a dummy pendulum which was designed to rest on a brass block, itself resting on the base of the stand. The pendulums, on the other hand, hung freely from their agate planes. Under normal Observatory conditions, where the change in air temperature is slow, this thermometer will represent with sufficient accuracy the temperature at the mid-point on the pendulum stem. Under unfavourable conditions, however, when the temperature is rapidly changing, the pendulum temperature must lag behind the observed temperature by an amount dependent on the rate of change. At all the field stations, except Winter Quarters and Christchurch, 1910, the question of lag does not crop up. Here, however, it assumes considerable importance, and special precautions must be taken either to free the apparatus from this source of error or to allow a correction for it The correction for lag which has been applied by the Potsdam observers is $+25 \times 10^{-7}$ sec. for a rise in temperature of 1° C. per hour. This is the correction which has been applied to the observations at Potsdam and at Christchurch in 1910.

The first change was made at the conclusion of Cape Evans, Series A, by the manufacture of a cork base-plate for the dummy pendulum, so that this was no longer in metallic connection with the base of the stand. This, it was thought, would cause the dummy pendulum to be at sensibly the same temperature as the working pendulums, so that the observed temperature could be assumed to be correct in all conditions of lag.

* Last four observations only.

To investigate the point more closely, a further modification was introduced at the commencement of series " C " by the use of three thermometers placed in different positions. It was at once observed that the mean reading of the two thermometers in air was by no means the same as the reading of the thermometer in the dummy pendulum. With rising temperature, the latter gave a lower reading than the mean of the air thermometers, not the reverse as would have been the case if the dummy pendulum was in metallic connection with the base of the instrument. It was also interesting to note that the considerable temperature gradient from floor to roof in the hut was reflected in a similar temperature gradient within the pendulum case, sometimes as much as $\frac{1}{2}°$ C. in 20 cms. vertical height.

As an example of the readings obtained, the uncorrected temperature observations of Series " D " are given in Table LXV, the corrections being, however, applied in the last column.

TABLE LXV.

No. 41204.	Δθ.	No. 41203.	Δθ.	No. 29110.	Δθ.	Mean Temp.
5°·06 C.	+·41° C.	4°·86 C.	+·38° C.	5°·65 C.	+·32° C.	5°·18 C.
5 ·41	+·31	5 ·20	+·32	5 ·97	+·32	5 ·51
5 ·69	+·24	5 ·51	+·29	6 ·26	+·26	5 ·81
3 ·22	+·11	3 ·16	+·08	3 ·52	+·15	3 ·28
3 ·34	+·07	3 ·28	+·13	3 ·69	+·18	3 ·42
3 ·50	+·21	3 ·42	+·16	3 ·82	+·09	3 ·56
5 ·01	−·02	4 ·98	+·06	5 ·31	−·18	5 ·10
4 ·92	−·16	4 ·98	−·04	5 ·16	−·18	5 ·01
4 ·74	−·20	4 ·88	−·16	4 ·93	−·28	4 ·81
3 ·09	−·24	3 ·24	−·28	3 ·12	−·22	3 ·13
2 ·88	−·17	3 ·02	−·16	2 ·92	−·17	2 ·92
2 ·72	−·17	2 ·84	−·19	2 ·77	−·14	2 ·76
4 ·26	+·25	4 ·15	+·18	4 ·70	+·32	4 ·36
4 ·50	+·23	4 ·35	+·22	5 ·04	+·35	4 ·62
5 ·00	+·41	4 ·77	+·37	5 ·60	+·44	5 ·11
5 ·34	+·29	5 ·13	+·34	5 ·96	+·29	5 ·46
2 ·13	+·32	1 ·98	+·28	2 ·58	+·43	2 ·21
2 ·44	+·26	2 ·26	+·30	2 ·96	+·33	2 ·53
2 ·77	+·36	2 ·55	+·33	3 ·28	+·33	2 ·85
4 ·41	−·02	4 ·45	−·04	4 ·66	+·05	4 ·49
4 ·42	+·05	4 ·43	+·01	4 ·75	+·12	4 ·52
4 ·52	+·13	4 ·47	+·08	4 ·90	+·19	4 ·62
4 ·07	+·00	4 ·20	−·09	4 ·28	−·03	4 ·17
4 ·05	−·04	4 ·12	−·07	4 ·28	+·01	4 ·14
4 ·04	+·03	4 ·10	+·01	4 ·32	+·09	4 ·14

TABLE LXV (continued).

No. 41201.	$\Delta\theta$.	No. 41203.	$\Delta\theta$.	No. 29110.	$\Delta\theta$.	Mean Temp.
4°·96 C.	+·19° C.	4°·87 C.	+·19° C.	5°·38 C.	+·26 C.	5·06 C.
5·08	+·07	5·02	+·09	5·50	—·02	5·19
5·16	+·03	5·16	+·06	5·44	+·00	5·24
3·23	+·10	3·16	+·10	3·51	+·22	3·28
3·32	+·07	3·25	+·08	3·64	+·04	3·38
3·38	+·05	3·35	+·10	3·68	+·05	3·45
5·11	+·18	5·00	+·22	5·60	+·13	5·22
5·24	+·09	5·18	+·12	5·69	+·06	5·36
5·33	+·08	5·30	+·13	5·75	+·06	5·45

Thermometer No. 41204 .. .. *erect—bulb low.*

,, ,, 29110 .. .. *inverted—bulb high.*

,, ,, 41203 .. .. *in dummy pendulum—bulb low.*

In this Table, the reading of each thermometer is given and the change $\Delta\theta$ in the thermometer reading during the swing of a single pendulum. From these figures are calculated the difference between the thermometer reading in the dummy pendulum (No. 41203) and the mean of all three=C. For convenience of calculation the observations are meaned for the three swings constituting a set. A formula has been assumed to hold between the difference C, the mean change in temperature $\left(= K_1 \cdot \frac{d\theta}{dt}\right)$ during the observation of a set (each of duration 40 mins.), and the mean difference between the reading of the upper and lower thermometers $= K_2 \cdot \frac{d\theta}{dh}$. The simple relation is—

$$C = A\,K_2 \cdot \frac{d\theta}{dh} + BK_1 \cdot \frac{d\theta}{dt}.$$

By the usual method, the observational and normal equations are formed, leading to the most probable values—A=0·214 and B=0·532. C is positive when the mean of all three thermometers is greater than the temperature registered in the dummy pendulum.

The comparison of the calculated and observed values of C are given below:—

	Calculated	and	Observed Values of C.
Series D, Cape Evans ..	0·30 C.		0·31 C.
	0·13		0·13
	0·03		0·03
	—0·10		—0·09
	0·26		0·26
	0·26		0·27
	0·08		0·09
	—0·02		—0·02
	0·14		0·14
	0·11		0·12
	0·18		0·18

Table LXVI gives the temperatures of observation at the various stations together with the change of temperature $d\theta$ during the 40 minutes the pendulum was under observation. The lag correction is then calculated from the lag constant of $25° \times 10^{-7}$ sec per degree Cent. per hour. Only in the case of Christchurch, 1910, is the lag correction appreciable, since the first two sets of observations at Cape Evans have to be neglected in any case.

TABLE LXVI.

	No. 5. $d\theta$.	No. 7. $d\theta$.	No. 21. $d\theta$.
Potsdam I	13°·23 C.+·02	13°·26 C.+·04	13°·24 C.+·00
	·26 +·04	·30 +·02	·22 +·04
	·38 +·02	·40 +·02	·38 +·00
	·36 +·02	·38 +·02	·36 +·00
	·48 +·03	·51 +·01	·48 +·00
	·46 +·02	·48 +·04	·44 +·02
	·54 +·02	·56 +·02	·52 +·02
	·70 +·02	·72 +·00	·66 +·04
	·62 +·04	·66 +·02	·60 +·02
	·70 +·01	·71 +·03	·68 +·02
Mean	13°·474 C.+·024	13°·498 C.+·022	13°·458 C.+·016
		Mean ... 13°·477 C.+·02 *Correction* +1.	
Potsdam II... ...	14°·60 C.+·00	14°·64 C.+·03	14°·61 C.—·01
	·49 +·02	·47 +·00	·47 +·02
	·54 +·01	·57 +·02	·55 +·02
	·53 —·01	·54 +·02	·52 +·02
	·66 +·03	·71 +·03	·69 +·02
	·47 +·02	·51 +·02	·47 ·00
	·69 —·01	·68 +·01	·68 ·00
	·48 +·01	·48 +·03	·48 ·00
Mean	14°·56 C.+·01	14°·575 C.+·02	14°·56 C.+·01
		Mean ... 14°·565 C.+·01 *Correction, Zero.*	

TABLE LXVI (continued).

	No. 5.	No. 7.	No. 21.
Wellington... ...	15°·10 C.— ·01 14 ·92 ·00 15 ·11 ·00 15 ·20 ·00 15 ·22 —·01	15°·08 C.—·01 14 ·92 —·01 15 ·10 —·01 15 ·20 ·00 15 ·16 —·02	15°·09 C.—·01 14 ·92 +·01 15 ·11 —·01 15 ·20 ·00 15 ·19 —·03
Mean	15°·11 C.— ·01	15°·09 C.—·01	15°·10 C.— ·01
		Mean ... 15°·10 C.—·01 *Correction, Zero.*	
Melbourne	16°·31 C. ·00 ·48 +·02 ·36 —·01 ·60 +·01 ·51 ·00 ·85 ·00	16°·32 C.+·01 ·52 —·05 ·38 +·03 ·56 —·01 ·53 +·02 ·88 —·04	16°·31 C.+·01 ·48 —·03 ·37 +·01 ·57 +·01 ·51 +·01 ·85 ·00
Mean	16°·52 C.+·01	16°·53 C.— ·01	16°·515 C. ± ·00
		Mean ... 16°·52 C. ± ·00 *Correction, Zero.*	
Christchurch, 1913	15°·84 C.— ·02 ·80 +·02 ·69 ·00 ·70 —·01 ·33 ·00 ·38 +·02	15°·82 C.—·01 ·80 —·01 ·70 +·01 ·71 ·00 ·33 ·00 ·35 ·00	15°·89 C.—·04 ·83 +·04 ·69 —·01 ·72 +·01 ·33 ·00 ·36 +·01
		Mean ... 15°·626 C. ±·00 *Correction, Zero.*	

By the method of taking temperatures the lag is assumed to be nil for Cape Evans "C" and "D."

In the case of the observations at Christchurch, in 1910, it was found necessary to calculate the corrections for the period of swing of each single pendulum, the change of temperature shown by the thermometer in the dummy pendulum *per hour* being given in this case in column 1 and the correction applied in column 2.

Christchurch, 1910.

	Rise of Temperature per hour.	Correction applied.
No. 5	0°·95 C.	$+24 \times 10^{-7}$ sec.
	0 ·83	+21
	0 ·23	+ 6
	0 ·49	+12

	Rise of Temperature per hour.	Correction applied.
No. 7	1°·18 C.	$+30\times10^{-7}$ sec.
	0 ·49	+12
	0 ·64	+16
	0 ·28	+ 7
No. 21	0°·59 C.	+15
	0 ·66	+16
	0 ·47	+12
	0 ·42	+10

Probable Errors of the Final Results.

In discussing the results of the observations, calculations have been made in each case which give criteria for the accuracy of these observations. These criteria do not show, however, the possible error of the observations, and are chiefly of service in estimating the degree of reliability which can be placed on the final arithmetical means.

The Table below gives the values obtained :—

Table LXVII.

	p_m.	e_m.	Mean of e_x.	$\bar{e}_m$.
Potsdam I ...	$0\cdot6\times10^{-7}$ sec.	$1\cdot9\times10^{-7}$ sec.	$3\cdot6\times10^{-7}$ sec.	$3\cdot1\times10^{-7}$ sec.
" II ...	1·0	3·0	3·8	2·5
Cape Evans A ...	5·2	12·9	16·4	10·7
" B ...	3·3	7·3	9·0	4·2
" C ...	2·0	5·3	6·1	3·6
" D ...	2·3	7·4	10·5	7·7
Wellington ...	2·0	3·8	6·2	4·6
Melbourne	0·6	1·6	5·9	5·8
Christchurch, 1910	16·6	33·3	36·0	7·3
" 1913	2·7	5·4	7·0	7·1

Here, e_x is the probable error in the time of swing of the pendulum x, swung once.

e_m is the probable error in the time of one swing of the mean pendulum.*

$\bar{e}_m$ is the mean value of the probable errors calculated from the differences between the mean and each pendulum, while p_m is the probable error of the mean value of all swings of the mean pendulum.

It will be clear that the method of derivation of these figures allows a comparison to be made which enables one to obtain some insight into the causes of the errors observed. The most important errors to which the observations at field stations were

* The time of swing of the mean pendulum is the mean of the times of swing of the three pendulums numbered 5, 7 and 21.

subject, were (apart from errors in the time observations) caused by unevenness of clock rate, and it was found that these irregularities were particularly serious immediately after the clock was rewound, so that the first observations often had to be discarded.

Whatever may be the cause of the irregularities in clock rate, it is clear that they may affect the numbers given in the Table above in different degree. Thus, if the clock rate remains constant during the whole course of the observations (the clock being rated only at the beginning and end of the observations), there is no reason why the figures given in the last two columns should notably differ from one another; if the clock rate remains constant during the period involved in swinging all three pendulums (one set), but has a different value from one set to another, the third column should show higher values than the last. Significantly higher values are, in fact, shown in the majority of cases, especially at Cape Evans and for Christchurch, 1910, where big differences exist between the numbers in these two columns. The reason can plausibly be put down to this cause, and where such differences do not exist, it may be inferred that the value in the last column gives a good measure of the accuracy of comparison between pendulums and clock.

The difference between p_m and e_m is, of course, entirely conditioned by the number of sets observed.

Judged by the values of e_x alone, the most satisfactory observations were, in order, those of Potsdam I, Potsdam II, Melbourne, Cape Evans C and Wellington. The Cape Evans observations (series C) were, however, clearly vitiated by irregular clock rate and, if this had not been the case, might have ranked still higher.

The values of p_m do not, however, represent the whole probable error of the final result, for they do not adequately include probable errors connected with :—

(1) The determination of the flexure correction.

(2) The determination of the temperature constants of the pendulums.

(3) The determination of the density constants for the pendulums.

(4) The application of the correction for temperature lag.

(5) The determination of the clock rate.

(6) The changes in the pendulums during the period between the initial and the final observations at Potsdam.

(7) The determination of the time of swing at Potsdam, the base station.

Evaluation of the Probable Errors.

(1) *Probable error of the flexure correction.*—This has been already worked out for the different field stations.

(2) and (3) The *probable errors of the determination of temperature and barometer constants* are only of importance when the temperature and barometer readings at the field stations are different from those recorded during the base station observations.

In Table LXVIII, the mean temperature and barometer readings are put down for all the stations, together with the differences Δ from the mean of the Potsdam observations.

TABLE LXVIII.

	Mean temperature.		Mean barometer.	
Potsdam I	13°·48 C.		753·9 mms.	
,, II	14°·56		750·3	
Potsdam (mean) ...	(14°·02)	Δ	(752·1) mms.	Δ
Cape Evans "C" ...	3°·16	=10°·86 C.	736·2	=15·9 mms.
,, "D" ...	4°·09	9°·93	739·7	=12·4
Wellington	15°·10	1°·08	747·7	= 4·4
Melbourne	16°·52	2°·50	767·7	=15·6
Christchurch, 1910 ...	19°·90	5°·88	760·8	= 8·7
,, 1913 ...	15°·52	1°·50	761·9	= 9·8

From pages 8 and 9, it is seen that the mean probable error of the determination of the temperature constant is $\pm 0{\cdot}07 \times 10^{-7}$ sec. and of the pressure constant $\pm 6{\cdot}8 \times 10^{-7}$ sec.

From these values, we may calculate for the different stations—

			For temperature and for	barometer constants.
Cape Evans "C"—probable error		..	$\pm 0{\cdot}8 \times 10^{-7}$ sec.	$\pm 0{\cdot}1 \times 10^{-7}$ sec.
,, "D"	,,	..	0·7	0·1
Wellington	,,	..	0·1	less than 0·1
Melbourne	,,	..	0·2	0·1
Christchurch, 1910	,,	..	0·4	less than 0·1
,, 1913	,,	..	0·1	less than 0·1

(4) *Probable error of lag correction.*—It may with confidence, I think, be assumed that no correction for lag needs to be applied in the case of the observations made subsequent to the replacement of the brass disc, upon which the dummy pendulum rested, by a disc of cork.

The brass disc was only used for the observations at Potsdam I, Christchurch, 1910, and Cape Evans (A). The error in assuming a lag correction of 25×10^{-7} sec. per degree per hour for the first is inappreciable, but may be significant in the case of Cape Evans (A) and particularly Christchurch, 1910. Of these, the former series is neglected in forming the final mean, while the errors of the latter cannot be estimated, though, in any case, the probable errors due to this cause must be insignificant in comparison with errors connected with the rating of the clock.

(5) *The determination of the probable error of the correction for clock rate.*—At Potsdam, the probable error of the rate may be taken as not greater than $\pm 0{\cdot}01$ sec., which corresponds to a probable error in the correction to time of swing $= \pm 0{\cdot}6 \times 10^{-7}$ sec.

The probable errors of rates at Wellington, Melbourne and Christchurch, 1913, may be taken as :—

Wellington* (about)	$\pm 0 \cdot 01$ sec. daily—	correction to	time of	swing	$\pm 0 \cdot 6 \times 10^{-7}$ sec.
Melbourne* (about)	$\pm 0 \cdot 01$	,,	,,	,,	$0 \cdot 6 \times 10^{-7}$ sec.
Christchurch, 1913 (about)	$\pm 0 \cdot 04$	,,	,,	,,	$2 \cdot 4 \times 10^{-7}$ sec.

At Cape Evans, the error of the clock rate cannot be calculated from the time observations alone, since, in working these out, a constant azimuth has been taken which is not calculated simply from the sights. The assumption that the direction of the azimuth mark remains unchanged during the course of the observations is quite justifiable, but the method of obtaining the value of the azimuth of the fixed mark is not at all free from objection. On the other hand, if the same stars are observed each night $\left[\text{or stars with the same mean value of } K = \frac{\sin(\phi-\delta)}{\cos\delta}\right]$, the error introduced by an error in the assumed azimuth is inappreciable. For this reason, the probable error of the clock rate can be calculated directly from the observations in the case of series D.

Thus, probable error of observation on Aug. 12th, $\pm 0 \cdot 08$ sec. ; on Aug. 18th, $\pm 0 \cdot 25$ sec.

Probable error of 6-day rate $= \sqrt{(0 \cdot 08)^2 + (0 \cdot 25)^2} = \pm 0 \cdot 26$ sec., or,

Probable error of daily rate $= \pm 0 \cdot 04$ sec., which means a probable error of $2 \cdot 4 \times 10^{-7}$ sec. in time of swing.

The case of series "C" is more complicated. Here, the probable error of the azimuth constant may be taken at $\pm 2 \cdot 0$ sec. The azimuth corrections calculated for an azimuth constant of $-7 \cdot 05$ sec. are :—

			These become, when the azimuth constant is reduced by $2 \cdot 0$ sec.		
July 12th	..	$-8 \cdot 12$ sec.	July 12th	..	$-5 \cdot 83$ sec.
,, 14th	..	$-7 \cdot 98$,,	,, 14th	..	$-5 \cdot 73$,,
,, 15th	..	$-7 \cdot 98$,,	,, 15th	..	$-5 \cdot 72$,,
,, 16th	..	$-7 \cdot 70$,,	,, 16th	..	$-5 \cdot 51$,,

The changes in daily rate due to such an error in the azimuth constant therefore amount to

$-0 \cdot 02$, $+0 \cdot 01$ and $-0 \cdot 07$ sec. for the three intervals.

We may take the probable error of the observations for rate as

$$\sqrt{(0 \cdot 25)^2 + (0 \cdot 08)^2} = \pm 0 \cdot 26 \text{ sec.}$$

in an interval of $3\frac{1}{2}$ days. This gives a probable error for daily rate of $\pm 0 \cdot 07$ sec.

* A calculation of the actual probable errors gives somewhat lower values ($\pm 0 \cdot 006$ sec.). The above figures may be taken as the upper limits.

Introducing the uncertainty in the azimuth constant, the total probable error of the daily rate is—

$$\sqrt{(0\cdot 07)^2+(0\cdot 02)^2}$$

$$\sqrt{(0\cdot 07)^2+(0\cdot 01)^2}$$

and

$$\sqrt{(0\cdot 07)^2+(0\cdot 07)^2},\text{ for the three intervals.}$$

The maximum probable error is $1\cdot 0$ sec., corresponding to 6×10^{-7} sec. in the time of swing.

As regards the observations at Cape Evans in 1911 (series A and B), it is quite impossible to obtain any indication of the probable error in clock rate from the observations for time and, for this reason, these two series have been neglected. It is interesting, however, to note that the final figures for series A are not very widely different from those of series C and D (which agree within the limits of the calculated probable errors).

On the other hand, the more consistent results of series B diverge widely from the remainder, and indicate a constant error in the applied rate which seems outside the bounds of probability. Other causes may, however, have contributed to the consistent errors which appear to be inherent in this series—for instance, the unsatisfactory working of the coincidence apparatus.

(6) *The probable error due to variability of the pendulums.*

From Table LXI, it is seen that only in the case of pendulum No. 7 was the time of swing at Potsdam the same on both occasions. Nos. 21 and 5 had on the second occasion, times of swing 16×10^{-7} sec. and 11×10^{-7} sec. less, respectively, than on the first occasion.

The changes are not sufficiently definite to enable one to say exactly when they occurred, but such changes are usually treated and evaluated as errors of an accidental type, which change from station to station and are constant during all the observations of the station.

A value μ^2 is first calculated from the data in Tables III, XI, etc., giving the squares of the differences of each observation by each pendulum from the mean of the station for each pendulum. These squares, $\Sigma\,(vv)$, are then summed for each station and these sums, $\Sigma\,(VV)$, are given in Table LXIX below :—

Table LXIX.—Values of $\Sigma\,(VV)$.

	No. 5.	No. 7.	No. 21.	Number of sets —n.
Potsdam I	288	394	158	10
Cape Evans, A ...	1818	6813	1600	6
„ B ...	544	1092	762	5
„ C ...	960	207	496	7
„ D ...	2541	1558	2688	10
Wellington ...	472	598	86	5
Melbourne	818	175	316	6
Potsdam II ...	459	41	294	8
$\Sigma\Sigma\,(VV)$ ...	7900	10,878	6400	$[n]$ 57

Then $\mu^2 = \dfrac{\Sigma\Sigma\,(VV)}{3\,([n]-r)}$; where $\Sigma\Sigma\,(VV)$ represents the sum of the squares of all differences for all pendulums, $[n]$ the total number of sets, and r the total number of stations. In this case, $\mu^2 = 171 \times 10^{-14}$.

Turning next to Table LXIII, we form the differences v^1 between the mean value of (M—5), (M—7) and (21—M) for all stations and for each single station. The squares of these differences are given in the last column of Table LXX.

TABLE LXX.—Values of v' and $\Sigma\,(v'v')$.

	M—5.	M—7.	21—M.	$\Sigma\,(v'v')$.
Potsdam I	+1	+6	+7	86
Cape Evans, A ...	+3	−5	−1	35
,, B ...	+7	−3	+6	94
,, C ...	−6	−1	−6	73
,, D ...	−9	+4	−7	146
Wellington ...	+6	−1	+5	62
Melbourne	−2	+1	−2	9
Potsdam II ...	+3	−3	0	18
				$[v'v'] = 523 \times 10^{-14}$

Following the method of calculation used by Borrass,* we then put

$$[v'v'] = 2\mu^2\,\frac{r-1}{r}\,\Sigma\,\frac{1}{n_\rho} + 2\,(r-1)\,\lambda^2.$$

Where n_ρ is the number of sets observed at the station ρ and λ^2 is the square of the probable error contributed by the variability of one pendulum.

Substituting the values found, we obtain

$$14\lambda^2 = 171 \times 10^{-14},$$

or

$$\lambda^2 = 12{\cdot}2 \times 10^{-14},$$

and

$$\lambda = 3{\cdot}5 \times 10^{-7}\ \text{sec.}$$

For the mean of three pendulums, this value of λ has to be divided by

$$\sqrt{3},\ \text{giving}\ \lambda = 2{\cdot}0 \times 10^{-7}\ \text{sec.},$$

which represents the contribution to the final probable error due to variability of the pendulum from station to station.

Clearly, this figure can lay no great claim to accuracy, in view of the variation in observing conditions and accuracy from station to station, but it is difficult to see

* Borrass, 'Relative Bestimmungen der Intensität der Schwerkraft.—Veröffent. des Kgl. Preuss. Geod. Inst.,' Neue Folge, Nr. 23.

how a better value can be derived. The uncertainty should not, however, be more than this in the case of a station such as Melbourne.

(7) *Probable error of the Potsdam observations.*

Including the error due to variability of the pendulums, the probable error of the value of the Potsdam mean works out to less than $\pm 2\cdot0 \times 10^{-7}$ sec., which we will therefore take as the maximum value.

The final probable error of the determination of the time of swing at the field stations we will denote by K,

$$\text{where } K = \sqrt{(1)^2 + (2)^2 + (3)^2 + + - + (7)^2 + p_m^{\ 2}}.$$

For convenience, these values are put down in Table LXXI, in units of the 7th decimal place of a second.

TABLE LXXI.*

	p_m.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	K.
Cape Evans, "C" ...	2·0	0·5	0·8	0·1	0	6·0	2·0	2·0	$7\cdot0 \times 10^{-7}$ sec.
,, "D" ...	2·3	0·5	0·7	0·1	0	2·4	2·0	2·0	4·5
Wellington	2·0	0·4	0·1	0·1	0	0·6	2·0	2·0	3·5
Melbourne	0·6	0·5	0·2	0·1	0	0·6	2·0	2·0	3·0

From this Table, it will be seen that the columns numbered (5) and (6)—the errors of clock rate and the variability of the pendulums—and the columns headed p_m and (7) are those chiefly effective in the formation of the probable error of the whole determination. Thus, the Cape Evans observations have a large probable error largely due to the poorness of the observations for clock rate. In this respect, the Cape Evans results are disappointing, for all the care bestowed on the technique of the observations was of no avail. In the Antarctic, the unfortunate transit instrument was blamed for many troubles—often unjustly† ; but, at least, the burden of the blame for the high value of K, it can in no way escape.

THE FINAL RESULTS.

Table LXXII is formed after applying the correction for lag to the Potsdam I observations, and a further correction to both the Potsdam Series, in order to reduce the observations in the cellar to the standard position on pillar No. 32 in the *Pendelsaal.* This amounts to an *addition* of 3×10^{-7} sec. to the observed time of swing.

* The figures for Christchurch have not been evaluated in view of the discordant results by the different pendulums.

† The seamen used to declare that the setting up of the transit instrument was an unfailing sign of approaching blizzards—as, indeed, it usually was.

Table LXXII.

	No. 5.	No. 7.	No. 21.	Mean.
Potsdam I, /10 ...	0·5083396	0·5083140	0·5097464	0·5088000
,, II, /13 ...	385	140	448	7991
Mean	390	140	456	7996
Cape Evans, "C"	0·5078973	0·5078717	0·5093009	0·5083566
,, "D"	973	709	005	563
Wellington ...	0·5085975	0·5085731	0·5100053	0·5090586
Melbourne	0·5086721	0·5086467	0·5100786	0·5091325

For the calculation of the value of gravity at the field stations the formula

$$g_s = \left(\frac{S_p}{S_s}\right)^2 g_p$$

is used, where g_s and g_p are the values of "g" at the station and at Potsdam, respectively, and S_s and S_p are the corresponding periods of swing.

The value of g_p is taken as 981·292 cms. per sec. per sec. for pillar 32 in the

Addendum to Page 91.

The assumed value of $g_p = 981{\cdot}292$ is that given by Hecker (*Veröffentlichung d. Königl. Preusz. Geodät. Instit., Neue Folge, No.* 16). The value generally adopted, the result of careful observations made at Potsdam with the reversible pendulum, is 981·274 ± ·003 (Kühnen and Furtwängler, *Veröffent. d. Königl. Preusz. Geodät. Instit., Neue Folge, No.* 27). The latter figure is that upon which are based the values of g found by Bernacchi at Christchurch, Melbourne, and at the "Discovery" Winter Quarters, taking the value at Kew, the base station for the "Discovery" Expedition, as 981·200.

The differences between our values and those of Bernacchi at these stations are partly accounted for by this fact.

The probable errors of the final result are :—

For Cape Evans .. .. ±0·0023 cms. per sec. per sec.

Wellington .. .. ±0·0014

Melbourne .. .. ±0·0012

how a better value can be derived. The uncertainty should not, however, be more than this in the case of a station such as Melbourne.

(7) *Probable error of the Potsdam observations.*

Including the error due to variability of the pendulums, the probable error of the value of the Potsdam mean works out to less than $\pm 2{\cdot}0 \times 10^{-7}$ sec., which we will therefore take as the maximum value.

The final probable error of the determination of the time of swing at the field stations we will denote by K,

$$\text{where } K = \sqrt{(1)^2 + (2)^2 + (3)^2 + + - + (7)^2 + p_m^{\ 2}}.$$

For convenience, these values are put down in Table LXXI, in units of the 7th decimal place of a second.

TABLE LXXI.*

	p_m.	(1)	(2)	(3)	(4)	(5)	(6)	(7)	K.
Cape Evans, "C" ...	2·0	0·5	0·8	0·1	0	6·0	2·0	2·0	$7{\cdot}0 \times 10^{-7}$ sec.
,, "D" ...	2·3	0·5	0·7	0·1	0	2·4	2·0	2·0	4·5
Wellington	2·0	0·4	0·1	0·1	0	0·6	2·0	2·0	3·5
Melbourne	0·6	0·5	0·2	0·1	0	0·6	2·0	2·0	3·0

to the standard position on pillar No. 32 in the *Pendelsaal*.

This amounts to an *addition* of 3×10^{-7} sec. to the observed time of swing.

* The figures for Christchurch have not been evaluated in view of the discordant results by the different pendulums.

† The seamen used to declare that the setting up of the transit instrument was an unfailing sign of approaching blizzards—as, indeed, it usually was.

TABLE LXXII.

	No. 5.	No. 7.	No. 21.	Mean.
Potsdam I, /10 ...	0·5083396	0·5083140	0·5097464	0·5088000
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Wellington ...	0·5085975	0·5085731	0·5100053	0·5090586
Melbourne	0·5086721	0·5086467	0·5100786	0·5091325

For the calculation of the value of gravity at the field stations the formula

$$g_s = \left(\frac{S_p}{S_s}\right)^2 g_p$$

is used, where g_s and g_p are the values of "g" at the station and at Potsdam, respectively, and S_s and S_p are the corresponding periods of swing.

The value of g_p is taken as 981·292 cms. per sec. per sec. for pillar 32 in the *Pendelsaal* at the Potsdam Geodetic Institute.

Table LXXIII is formed for each pendulum by the use of this formula.

TABLE LXXIII.

	No. 5.	No. 7.	No. 21.	Mean.
Potsdam (mean) ...	981·282	981·292	981·292	981·292 cms. per sec. per sec.
Cape Evans, "C" ...	981·999	983·002	983·006	983·003
,, "D" ...	982·999	983·005	983·008	983·001
Wellington	980·295	980·293	980·293	980·294
Melbourne	980·007	980·009	980·011	980·009
Christchurch, 1910 ...	(980·518)	980·528	980·533	(980·526)
,, 1913 ...	(980·571)	(980·551)	(980·542)	(980·557)

The probable errors of the final result are :—

For Cape Evans .. .. $\pm 0 \cdot 0023$ cms. per sec. per sec.

Wellington .. .. $\pm 0 \cdot 0014$

Melbourne .. .. $\pm 0 \cdot 0012$

Gravity at Melbourne.

Only at Melbourne has the value of "g" been accurately observed, the latest values referred to Potsdam being:—

$980 \cdot 003 \pm 0 \cdot 0014$	.. .. ..	Hecker, 1904.
$980 \cdot 003$	.. ..	Alessio, 1905.

It will be observed that our final value at Melbourne differs from that obtained by Hecker and that the gap between the two values is greater than the sum of the probable errors in the two cases.

The values obtained by Hecker with individual pendulums were 980·003, 980·005, 980·004, 980·001 and 980·003, the average difference for five pendulums, between Potsdam I and Potsdam II, being 8×10^{-7} sec., compared with 9×10^{-7} sec. in our observations.

Even if our Potsdam I observations are neglected, so that the final value is alone used for comparison with the Melbourne figures, the gap between the two observations for "g" at Melbourne remains 0·0045. The consistency of the values obtained by Hecker with his five pendulums seems convincing evidence that his value is unlikely to be wrong by more than 0·0015, but there is equally no reason to expect an error of more than 0·002 in our final value. Moreover, there is a gap of 0·002 between Hecker's maximum value with any pendulum and our minimum.

So long, therefore, as one assumes that—(1) the correct time of swing at Potsdam lies between the extremes of Potsdam I and Potsdam II, and (2) the value of "g" at Potsdam relative to that at Melbourne remains unchanged in course of time, one finds it difficult to reconcile the values obtained at Melbourne in the different years. The discrepancy is not a large one, but is sufficient in magnitude to raise a doubt as to the accuracy of the assumptions. Is, in fact, the ratio—"g" (Potsdam) to "g" (Melbourne)—the same at all times, or is there some other source of error, which has not been evaluated and which is comparable in magnitude with the calculated probable error* ?

Gravity at Cape Evans.

The observations at Cape Evans are closely comparable with the earlier observations by Bernacchi at the "Discovery" Winter Quarters, 15 miles further south. These earlier observations were not very accordant, and the difficulties connected with clock rate were even greater than those experienced at our own Winter Quarters. Still, the adopted mean of his observations gave the value "g" = 982·985, which is

* It is important to note that the probable errors calculated from the small number of observations available, can have little significance other than that of a rough measure of the consistency of the observations.

within reasonable measure of the values 983·004 and 983·003 found for the Cape Evans station.

The values found by Bernacchi with the three pendulums used by him were 982·970, 982·979 and 983·025. From the published figures, it is clear that little reliance can be placed on the value of the adopted mean, but it is interesting to note that Bernacchi's mean value at Melbourne was about 0·03 low, and that his Christchurch value, 980·512, is also somewhat lower than ours.

Attention should be drawn to the fact that the observations at Cape Evans in the first year have been neglected. It is quite impossible to determine the probable error of the observations in this first year and the conditions of observation were very unsatisfactory. The clock was hung in a very unfavourable position, the time observations were unsatisfactory and the coincidence apparatus was working very badly. In addition, the low temperature in the pendulum cave did not improve the observational conditions.

Of the two sets of observations made in the first winter, the first gives values for " g " not far removed from those obtained in the second year, but the times of swing in the second set are such as would correspond to an error in the daily clock rate of 0·8 sec.—an error which it is difficult to believe could have occurred. The agreement of the first set with the third and fourth (apparently within the probable error) is therefore a matter for satisfaction, but no explanation for the disagreement of the second set can be offered.

Gravity at Christchurch.

Observations were made by Bernacchi on the Discovery Expedition in 1901 and 1904, but little agreement is shown between the values for " g " in the different years or with the different pendulums. Unfortunately, the observations of the present expedition were not much more successful. Neither for the observations in 1910, nor for those in 1913, is it possible to calculate the probable error. On the first occasion, the observational conditions were wholly unsatisfactory and the values for time of swing may be in error by 20×10^{-7} sec., while the value obtained with pendulum No. 5 is obviously wrong and must be discarded. In the second year, no two pendulums gave satisfactory observations. The whole of the observations should therefore be discarded, but as the previous observations by Bernacchi all appear even more unsatisfactory, the value of " g " has been evaluated.

The corrected values were as follows :—

	No. 5.	No. 7.	No. 21.
Christchurch, 1910	(0·5085396) sec.	0·5085121 sec.	0·5099429 sec.
,, 1913	(0·5085259) ,,	(0·5085052) ,,	(0·5099405) ,,

The *best* one can hope for is that pendulum No. 21 was working satisfactorily in 1913, but no reliance can be placed on this. In all probability, the values obtained in 1910 and 1913 with No. 21 are in agreement within the limits of probable error.

By the use of these figures, the following values are obtained for " g " :—

	No. 5.	No. 7.	No. 21.
Christchurch, 1910 ..	(980·518)	980·528	980·533 cms. per sec. per sec.
,, 1913 ..	(980·571)	(980·554)	(980·542)

The most probable value I think is 980·534 (which is about 0·022 more than that obtained by Bernacchi*), with a probable uncertainty of $\pm 0 \cdot 010$.

It was at first the intention to compare the observed value of " g " with the value calculated from Helmert's formula, corrected for height above sea-level, for density of the earth's crust at the observing station, and for the attraction of neighbouring land masses, but this course appears undesirable in a report of this nature.

Hayford and other workers of the U.S. Coast and Geodetic Survey have shown that there is, in the United States, a tendency to isostatic compensation, and have derived figures for the most probable depth of compensation in the U.S., which varies according to the assumption as to the relation between compensation and depth, the data being insufficient to decide between different assumptions. This tendency towards isostatic compensation has been confirmed in other parts of the world, and it is clear that a closer approximation to compensation would be obtained if the further assumption were made that the depth of compensation varied from place to place.

The principle of isostasy can thus not be substantiated, though clearly a *tendency* to isostatic compensation exists. It appears to the writer that useful results can only be obtained from the application of the principle when large areas of the earth's surface are considered, the anomalies then outstanding at different places being most probably evidence of a tendency to uplift the earth's crust or to depress it. Certainly, if a tendency to isostatic compensation exists, but it is not complete, the values of " g " at any place must be dependent somewhat on the intensity of erosion at that place, or, in the Antarctic, largely on the intensity of glacierisation and the rate at which the ice masses on the continent increase or decrease.

The acceptance of this principle leads inevitably to question to what extent the ratio of " g " at two stations on the earth's surface will remain constant and independent of time, and it would certainly appear that the possibility of a measurable variation, even in quite short periods of time, should receive consideration.

October 15*th*, 1921.

* National Antarctic Expedition, 1901–1904—Physical Observations.

Table I.—Potsdam I.

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing.		Temperature.		Percentage Humidity.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for—					Reduced Time of Swing in Sidereal Seconds.
			Beginning.	End.	Beginning.	End.						Amplitude.	Tempera-ture.	Density.	Clock-rate.	Flexure.	
								May 18 and 19, 1910.									
	p.m.	secs.	′	′	° C.	° C.											
21	4·3	25·812	23·6	18·6	13·24	13·24	86	752·2	—3·5	0·940	0·5098767	—12	— 645	—605	—3	—51	0·5097451
5	5·0	30·031	21·0	15·8	13·24	13·26	86	752·2	—3·5	0·940	0·5084657	— 9	— 600	—605	—3	—43	0·5083397
7	5·7	30·103	27·6	18·5	13·26	13·30	86	752·3	—3·5	0·940	0·5084451	—13	— 652	—605	—3	—43	0·5083135
																	0·5087994
	a.m.																
21	8·1	25·810	23·2	18·5	13·22	13·26	86	753·0	—3·5	0·941	0·5098775	—12	— 645	—606	—3	—51	0·5097458
5	8·9	30·034	16·6	11·9	13·26	13·30	86	753·1	—3·5	0·941	0·5084648	— 5	— 602	—606	—3	—43	0·5083389
7	9·6	30·103	24·6	18·8	13·30	13·32	86	753·2	—3·5	0·941	0·5084451	—13	— 653	—606	—3	—43	0·5083133
																	0·5087993
								May 19 and 20, 1910.									
	p.m.																
21	5·0	25·809	22·6	17·9	13·38	13·38	86	752·4	—3·5	0·940	0·5098779	—11	— 652	—605	—1	—51	0·5097459
5	5·7	30·031	17·8	13·5	13·38	13·40	86	752·4	—3·5	0·940	0·5084657	— 7	— 607	—605	—1	—43	0·5083394
7	6·3	30·103	24·3	18·8	13·40	13·42	86	752·4	—3·5	0·940	0·5084451	—13	— 658	—605	—1	—43	0·5083131
																	0·5087995
	a.m.																
21	8·0	25·808	22·7	18·5	13·36	13·36	84	752·7	—3·5	0·940	0·5098783	—12	— 651	—605	—1	—51	0·5097463
5	8·6	30·033	18·2	13·8	13·36	13·38	84	752·6	—3·5	0·940	0·5084651	— 7	— 606	—605	—1	—43	0·5083389
7	9·3	31·102	25·1	19·3	13·38	13·40	84	752·6	—3·5	0·940	0·5084453	—13	— 657	—605	—1	—43	0·5083134
																	0·5087995
								May 20 and 21, 1910.									
	p.m.																
21	4·2	25·807	21·9	16·3	13·48	13·48	84	751·9	—3·5	0·940	0·5098787	—10	— 657	—605	—1	—51	0·5097463
5	4·9	30·030	19·3	13·5	13·48	13·51	84	751·9	—3·5	0·939	0·5084660	— 7	— 611	—605	—1	—43	0·5083393
7	5·6	30·098	21·6	18·2	13·51	13·52	84	751·9	—3·5	0·940	0·5084465	—12	— 663	—605	—1	—43	0·5083141
																	0·5087999
	a.m.																
21	7·9	25·807	22·8	18·3	13·44	13·46	83	754·1	—3·5	0·941	0·5098787	—12	— 656	—606	—1	—51	0·5097461
5	8·6	30·031	17·9	13·6	13·46	13·48	84	754·3	—3·5	0·941	0·5084657	— 7	— 610	—606	—1	—43	0·5083390
7	9·3	30·095	23·5	17·7	13·48	13·52	84	754·3	—3·5	0·941	0·5084473	—12	— 662	—606	—1	—43	0·5083149
																	0·5088000

Table I (continued).

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing.		Temperature.		Percentage Humidity.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for—					Reduced Time of Swing in Sidereal Seconds.
			Beginning.	End.	Beginning.	End.						Amplitude.	Tempera-ture.	Density.	Clock-rate.	Flexure.	
								May 23, 1910.									
	a.m.	secs.	′	′	° C.	° C.											
21	8·5	25·805	23·2	18·5	13·52	13·54	78	758·0	−3·3	0·946	0·5098794	−12	− 659	−609	+3	−51	0·5097466
5	9·2	30·030	16·8	12·7	13·54	13·56	78	758·0	−3·3	0·946	0·5084660	− 6	− 614	−609	+3	−43	0·5083391
7	9·8	30·097	23·2	16·8	13·56	13·58	78	758·0	−3·3	0·946	0·5084468	−11	− 666	−609	+3	−43	0·5083142
																	0·5088000
	p.m.																
21	5·3	25·806	22·9	18·2	13·66	13·70	78	756·5	−3·3	0·943	0·5098791	−12	− 667	−607	+3	−51	0·5097457
5	6·0	30·025	16·7	12·7	13·70	13·72	78	756·5	−3·3	0·943	0·5084674	− 6	− 621	−607	+3	−43	0·5083400
7	6·8	30·097	22·6	16·7	13·72	13·72	78	756·5	−3·3	0·943	0·5084468	−11	− 682	−607	+3	−43	0·5083128
																	0·5087995
								May 24, 1910.									
	a.m.																
21	8·5	25·805	23·2	18·2	13·60	13·62	78	755·6	−3·3	0·943	0·5098794	−12	− 663	−607	+1	−51	0·5097462
5	9·2	30·032	16·7	12·5	13·62	13·66	78	755·5	−3·3	0·942	0·5084654	− 6	− 617	−607	+1	−43	0·5083382
7	9·9	30·099	22·1	16·8	13·66	13·68	78	755·4	−3·3	0·942	0·5084462	−11	− 671	−607	+1	−43	0·5083131
																	0·5087992
	p.m.																
21	5·4	25·806	23·2	18·8	13·68	13·70	77	752·1	−3·3	0·938	0·5098791	−12	− 667	−604	+1	−51	0·5097458
5	6·1	30·027	16·6	11·7	13·70	13·71	77	752·2	−3·3	0·938	0·5084668	− 5	− 621	−604	+1	−43	0·5083396
7	6·8	30·099	23·7	16·1	13·71	13·74	77	752·2	−3·3	0·938	0·5084462	−12	− 674	−604	+1	−43	0·5083130
																	0·5087995

Table IX.—Potsdam II.

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing. Beginning.	Amplitude of Swing. End.	Temperature. Beginning.	Temperature. End.	Percentage Humidity.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for— Amplitude.	Corrections for— Temperature.	Corrections for— Density.	Corrections for— Clock-rate.	Corrections for— Flexure.	Reduced Time of Swing in Sidereal Seconds.
	h. m.																
	p.m.	s.	′	′	° C.	° C.				October 4, 1913							
5	3·30	30·020	18	14	14·60	14·60	78	752·2	—3·6	0·935	0·5084688	— 7	— 661	—602	— 8	—38	0·5083372
21	2·54	25·799	20	16	14·61	14·60	77	752·4	—3·6	0·935	0·5098818	— 9	— 712	—602	— 8	—48	0·5097439
7	4·52	30·081	18	14	14·64	14·67	78	751·7	—3·6	0·935	0·5084514	— 7	— 719	—602	— 8	—38	0·5083140
	a.m.									October 5.							
5	10·52	30·023	18	14	14·49	14·51	78	747·8	—3·6	0·930	0·5084679	— 7	— 657	—599	— 8	—38	0·5083370
21	10·15	25·801	21	17	14·47	14·49	78	747·8	—3·6	0·930	0·5098810	—10	— 706	—599	— 8	—48	0·5097439
7	9·40	30·086	18	13	14·47	14·47	78	747·8	—3·6	0·930	0·5084500	— 6	— 710	—599	— 8	—38	0·5083139
	p.m.																
5	5·35	30·017	20	15	14·54	14·55	80	748·2	—3·7	0·930	0·5084697	— 8	— 659	—599	— 8	—38	0·5083385
21	6·11	25·799	20	16	14·55	14·57	80	748·4	—3·7	0·930	0·5098818	— 9	— 710	—599	— 8	—48	0·5097444
7	6·48	30·086	18	13	14·57	14·59	80	748·4	—3·7	0·930	0·5084500	— 6	— 715	—599	— 8	—38	0·5083134
	a.m.									October 6.							
5	9·55	30·016	22	16	14·53	14·52	80	749·2	—3·7	0·931	0·5084700	—10	— 658	—600	— 9	—38	0·5083385
21	10·31	25·798	22	18	14·52	14·54	80	749·3	—3·7	0·931	0·5098822	—11	— 708	—600	— 9	—48	0·5097446
7	11·08	30·083	20	17	14·54	14·56	80	749·3	—3·7	0·931	0·5084508	— 9	— 714	—600	— 9	—38	0·5083138
	p.m.																
5	4·25	30·015	21	16	14·66	14·69	80	749·8	—3·7	0·932	0·5084713	— 9	— 665	—600	— 9	—38	0·5083392
21	5·00	25·795	21	17	14·69	14·71	80	750·1	—3·7	0·932	0·5098834	—10	— 716	—600	— 9	—48	0·5097451
7	5·38	30·080	20	15	14·71	14·74	80	750·3	—3·7	0·932	0·5084517	— 8	— 722	—600	— 9	—38	0·5083140
	a.m.									October 7.							
5	10·21	30·013	22	17	14·47	14·49	77	754·1	—3·6	0·938	0·5084708	—10	— 656	—604	— 9	—38	0·5083391
21	9·45	25·795	23	18	14·47	14·47	77	754·1	—3·6	0·938	0·5098834	—11	— 705	—604	— 9	—48	0·5097457
7	11·08	30·082	21	16	14·51	14·53	77	754·0	—3·6	0·938	0·5084511	— 9	— 713	—604	— 9	—38	0·5083138
	p.m.																
5	3·54	30·013	23	17	14·69	14·68	77	752·5	—3·6	0·935	0·5084708	—11	— 665	—602	— 10	—38	0·5083382
21	4·30	25·797	19	15	14·68	14·68	77	752·3	—3·6	0·935	0·5098826	— 8	— 715	—602	— 10	—48	0·5097443
7	5·09	30·081	21	16	14·68	14·69	77	752·1	—3·6	0·935	0·5084514	— 9	— 720	—602	— 10	—38	0·5083135
	a.m.									October 8.							
5	8·44	30·018	23	17	14·48	14·48	76	748·3	—3·5	0·931	0·5084694	—11	— 656	—600	— 11	—38	0·5083378
21	9·21	25·800	22	17	14·48	14·48	76	748·1	—3·5	0·931	0·5098814	—10	— 706	—600	— 11	—48	0·5097439
7	9·55	30·085	20	15	14·48	14·51	76	747·9	—3·5	0·931	0·5084503	— 8	— 711	—600	— 11	—38	0·5083135

TABLE XVII.—Christchurch, 1910.

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing.		Temperature.		Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for—					Reduced Time of Swing in Sidereal Seconds.
			Beginning.	End.	Beginning.	End.					Amplitude.	Tempera-ture.	Density.	Clock-rate.	Flexure.	
								November 18.								
	a.m.	s.	′	′	° C.	° C.										
21	8·48	25·290	20·4	15·7	+13·31	13·68	761·63	—2·4	0·952	0·5100846	— 8	— 658	—613	— 17	—94	0·5099456
5	9·30	29·303	28·6	21·1	+13·73	14·33	761·32	—2·6	0·950	0·5086797	—16	— 636	—612	— 17	—70	0·5085446
7	10·15	29·378	16·9	12·7	+14·44	15·21	761·12	—2·7	0·946	0·5086571	— 6	— 729	—609	— 17	—70	0·5085140
	p.m.															
5	4·00	29·200	15·2	11·9	+24·75	25·36	758·68	—3·5	0·910	0·5087108	— 5	—1136	—586	— 17	—70	0·5085294
21	4·51	25·180	15·7	12·4	+25·48	25·91	758·51	—3·2	0·908	0·5101295	— 5	—1251	—585	— 17	—94	0·5099343
7	5·34	29·233	14·4	10·8	+26·07	26·38	758·35	—3·2	0·906	0·5087008	— 4	—1288	—583	— 17	—70	0·5085046
								November 19.								
	a.m.															
5	8·07	29·269	14·9	11·0	+16·58	16·78	763·59	—2·5	0·944	0·5086900	— 4	— 756	—608	— 60	—70	0·5085402
21	8·59	25·246	15·7	12·0	+16·89	17·18	763·54	—2·6	0·942	0·5101027	— 5	— 831	—607	— 60	—94	0·5099430
7	9·44	29·325	18·6	13·9	+17·28	17·74	763·34	—2·7	0·940	0·5086730	— 7	— 860	—606	— 60	—70	0·5085127
	p.m.															
5	3·30	29·194	16·3	12·1	+22·30	22·61	760·16	—2·7	0·921	0·5087126	— 5	—1017	—593	— 60	—70	0·5085381
21	4·11	25·180	14·2	11·4	+22·69	22·92	759·85	—2·8	0·920	0·5101295	— 4	—1112	—592	— 60	—94	0·5099433
7	4·56	29·248	15·5	11·4	+22·95	23·14	759·45	—2·8	0·918	0·5086963	— 5	—1132	—591	— 60	—70	0·5085105

Table XXI.—Cape Evans, 1911. Series "A."

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing.		Temperature.		Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for—					Reduced Time of Swing in Sidereal Seconds.
			Beginning.	End.	Mean.	ΔT.					Amplitude.	Tempera-ture.	Density.	Clock-rate.	Flexure.	
	p.m.	s.	′	′	° C.	° C.		June 30.								
21	3·30	27·4958	14·8	11·4	—23·35	—·38	741·4	0·0	1·067	0·5092607	— 4	+1138	—687	+ 12	—22	0·5093044
5	4·20	32·2824	16·6	11·9	—23·00	—·24	740·9	0·0	1·065	0·5078660	— 5	+1042	—686	+ 12	16	0·5079007
7	5·25	32·4070	17·8	15·2	—22·75	—·07	740·2	0·0	1·063	0·5078353	— 7	+1116	—685	+ 12	-16	0·5078773
	a.m.							July 1.								
7	9·23	32·4319	12·7	8·3	—23·77	—·03	734·6	0·0	1·059	0·5078292	— 3	+1166	—682	+ 12	—16	0·5078769
21	10·18	27·5028	14·9	12·4	—23·73	—·07	734·9	0·0	1·059	0·5092583	— 5	+1157	—682	+ 12	—22	0·5093043
5	11·00	32·3016	16·4	11·9	—23·60	—·13	734·9	0·0	1·058	0·5078612	— 5	+1069	—681	+ 12	—16	0·5078991
	p.m.															
5	8·25	32·3192	12·5	8·4	—24·33	+·01	738·4	0·0	1·067	0·5078569	— 3	+1102	—687	+ 12	—16	0·5078977
21	9·18	27·5182	16·0	13·0	—24·30	—·10	738·9	0·0	1·067	0·5092530	— 5	+1184	—687	+ 12	—22	0·5093012
7	10·20	32·4562	12·3	8·7	—24·14	—·08	739·4	0·0	1·068	0·5078232	— 3	+1184	—688	+ 12	—16	0·5078721
	a.m.							July 2.								
7	9·38	32·4690	12·5	8·7	—24·15	—·04	747·6	0·0	1·080	0·5078201	— 3	+1185	—696	+ 12	—16	0·5078683
21	10·25	27·5003	16·4	12·7	—24·04	—·15	748·1	0·0	1·080	0·5092592	— 5	+1172	—696	+ 12	—22	0·5093053
5	11·13	32·3171	12·5	9·1	—23·87	—·18	748·8	0·0	1·080	0·5078574	— 3	+1081	—696	+ 12	—16	0·5078952
	p.m.															
5	8·37	32·3087	11·7	8·3	—23·86	—·09	752·1	0·0	1·085	0·5078595	— 3	+1081	—699	+ 12	—16	0·5078970
21	9·21	27·5077	16·3	12·2	—23·78	—·04	751·6	0·0	1·084	0·5092566	— 5	+1159	—698	+ 12	—22	0·5093012
7	10·00	32·4469	12·2	8·8	—23·72	—·08	751·1	0·0	1·083	0·5078255	— 3	+1164	—697	+ 12	—16	0·5078715
	a.m.							July 3.								
7	9·52	32·4291	12·2	8·5	—23·84	—·09	749·5	0·0	1·081	0·5078299	— 3	+1170	—696	+ 12	—16	0·5078766
21	10·30	27·5054	15·9	12·0	—23·78	—·06	749·3	0·0	1·080	0·5092574	— 5	+1159	—696	+ 12	—22	0·5093022
5	11·10	32·2997	13·1	9·3	—23·71	—·07	748·8	0·0	1·079	0·5078617	— 3	+1074	—695	+ 12	—16	0·5078989

TABLE XXVII.—Cape Evans, 1911. Series "B."

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing. Beginning.	Amplitude of Swing. End.	Temperature. Mean.	Temperature. Δt.	Percentage Humidity.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for— Amplitude.	Corrections for— Tempera-ture.	Corrections for— Density.	Corrections for— Clock-rate.	Corrections for— Flexure.	Reduced Time of Swing in Sidereal Seconds.
	a.m.	s.	′	′	° C.	° C.			August 16.								
21	10·09	27·5167	23·0	15·8	−26·70	−·12	95	741·7	−0·1	1·082	0·5092535	−10	+1301	−697	− 23	−20	0·5093086
5	11·00	32·3188	17·5	12·5	−26·47	−·11	95	741·9	−0·1	1·081	0·5078570	− 6	+1199	−696	− 23	−16	0·5079028
7	11·40	32·4500	24·8	17·5	−26·40	−·04	95	741·9	−0·1	1·081	0·5078247	−12	+1295	−696	− 23	−16	0·5078795
	p.m.																
7	4·10	32·4639	24·3	17·2	−26·43	−·05	95	741·6	−0·1	1·080	0·5078213	−12	+1297	−695	− 23	−16	0·5078764
21	5·00	27·5159	26·4	19·7	−26·37	−·07	95	741·2	−0·1	1·079	0·5092538	−14	+1285	−695	− 23	−20	0·5093071
5	5·40	32·3254	23·6	18·5	−26·32	−·03	95	741·2	−0·1	1·079	0·5078554	−12	+1192	−695	− 23	−16	0·5079000
	a.m.								August 17.								
5	10·00	32·3548	22·2	14·9	−26·46	−·04	95	738·4	−0·1	1·076	0·5078481	− 9	+1198	−693	− 23	−16	0·5078938
21	10·50	27·4981	26·2	19·7	−26·46	+·04	95	738·4	−0·1	1·076	0·5092599	−14	+1290	−693	− 23	−20	0·5093139
7	11·40	32·4654	24·8	17·6	−26·51	+·07	95	738·2	−0·1	1·076	0·5078210	−12	+1301	−693	− 23	−16	0·5078767
	p.m.																
7	4·30	32·4750	25·0	17·3	−26·71	−·06	95	738·4	−0·1	1·077	0·5078186	−12	+1311	−694	− 23	−16	0·5078752
21	5·15	27·5252	26·0	19·6	−26·62	−·05	95	738·6	−0·1	1·077	0·5092506	−14	+1297	−694	− 23	−20	0·5093052
5	6·00	32·3278	21·8	15·1	−26·58	−·02	95	739·2	−0·1	1·077	0·5078548	− 9	+1204	−694	− 23	−16	0·5079010
	a.m.								August 18.								
5	10·10	32·3326	24·3	17·1	−26·70	+·04	95	742·2	−0·1	1·082	0·5078536	−11	+1210	−697	− 23	−16	0·5078999
21	11·00	27·5206	26·6	20·1	−26·76	+·05	95	742·2	−0·1	1·082	0·5092522	−15	+1304	−697	− 23	−20	0·5093071
7	11·40	32·4678	23·5	16·6	−26·77	−·02	95	742·1	−0·1	1·082	0·5078204	−11	+1314	−697	− 23	−16	0·5078771
	p.m.																
7	4·30	32·4752	25·4	17·7	−26·95	+·02	95	742·3	−0·1	1·083	0·5078186	−13	+1322	−697	− 23	−16	0·5078759
21	5·10	27·5285	26·4	19·7	−26·98	+·02	95	742·4	−0·1	1·084	0·5092495	−14	+1315	−698	− 23	−20	0·5093055
5	5·50	32·3330	23·0	15·9	−26·99	−·01	95	742·4	−0·1	1·084	0·5078535	−11	+1223	−698	− 23	−16	0·5079010

TABLE XXXIII.—Cape Evans, 1912. Series "C."

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing.		Temperature.		Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for—					Reduced Time of Swing in Sidereal Seconds.
			Beginning.	End.	Mean.	Δt.					Amplitude.	Temperature.	Density.	Clock-rate.	Flexure.	
	a.m.	s.	′	′	° C.	° C.		July 13.								
21	10·22	27·1416	13·1	9·8	+3·40	—·07	743·4	−2·6	0·964	0·5093838	− 3	− 166	−621	+ 8	−36	0·5093020
5	11·10	31·8382	23·8	16·6	+3·22	—·27	743·7	−2·6	0·964	0·5079775	−11	− 146	−621	+ 8	−24	0·5078981
7	12·00	31·9407	17·5	12·2	+2·98	—·18	743·4	−2·6	0·964	0·5079515	− 6	− 146	−621	+ 8	−24	0·5078726
	p.m.															
7	17·10	31·9452	16·9	11·9	+2·84	+·14	742·9	−2·6	0·963	0·5079505	− 5	− 139	−620	+ 8	−24	0·5078723
21	19·24	27·1439	17·6	13·2	+3·36	+·25	742·8	−2·6	0·963	0·5093830	− 6	− 161	−620	+ 8	−36	0·5093012
5	18·00	31·8403	21·5	15·0	+2·98	+·15	742·8	−2·6	0·963	0·5079770	− 9	− 135	−620	+ 8	−24	0·5078990
	a.m.							July 14.								
7	10·00	31·9366	17·0	12·1	+3·64	—·05	739·6	−2·6	0·957	0·5079525	− 5	− 179	−616	+ 8	−24	0·5078709
5	11·30	31·8362	21·1	15·6	+3·52	—·10	739·4	−2·6	0·957	0·5079780	− 9	− 159	−616	+ 8	−24	0·5078980
21	10·45	27·1416	19·1	13·4	+3·60	—·04	739·7	−2·6	0·957	0·5093838	− 7	− 175	−616	+ 8	−36	0·5093012
	p.m.															
5	18·40	31·8459	22·1	15·6	+3·76	+·09	738·4	−2·6	0·954	0·5079755	−10	− 170	−614	+ 29	−24	0·5078966
21	19·24	27·1470	18·1	13·8	+3·81	+·02	738·0	−2·6	0·954	0·5093819	− 7	− 186	−614	+ 29	−36	0·5093005
7	20·10	31·9372	23·6	16·8	+3·82	·00	737·7	−2·6	0·954	0·5079524	−11	− 187	−614	+ 29	−24	0·5078717
	a.m.							July 15.								
5	10·10	31·8978	23·6	16·8	+1·14	+·20	730·7	−2·6	0·953	0·5079623	−11	− 52	−614	+ 29	−21	0·5078951
21	11·00	27·1854	18·1	13·8	+1·34	+·19	730·5	−2·6	0·953	0·5093684	− 7	− 65	−614	+ 29	−36	0·5092991
7	11·50	31·9815	22·5	16·1	+1·56	+·25	730·4	−2·6	0·953	0·5079412	−10	− 77	−614	+ 29	−24	0·5078716
	p.m.															
5	10·40	31·8672	23·1	16·1	+2·61	+·33	730·6	−2·6	0·947	0·5079701	−10	− 118	−610	+ 29	−21	0·5078968
21	9·20	27·1602	17·8	13·5	+2·89	+·24	730·8	−2·6	0·947	0·5093773	− 7	− 141	−610	+ 29	−36	0·5093008
7	10·00	31·9517	22·5	16·1	+3·16	+·28	730·7	−2·6	0·947	0·5079487	−10	− 155	−610	+ 29	−24	0·5078717
	a.m.							July 16.								
7	10·00	31·9626	21·6	15·4	+2·42	+·05	728·1	−2·6	0·946	0·5079459	− 9	− 119	−609	+ 14	−21	0·5078712
21	10·45	27·1608	17·5	13·2	+2·48	+·05	728·4	−2·6	0·946	0·5093771	− 6	− 121	−609	+ 14	−36	0·5093013
5	11·30	31·8611	24·0	16·8	+2·51	+·02	728·6	−2·6	0·946	0·5079717	−11	− 114	−609	+ 14	−24	0·5078973

TABLE XXXIX.—Cape Evans, 1912. Series "D."

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing. Beginning.	Amplitude of Swing. End.	Temperature. Mean.	Temperature. Δt.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for— Amplitude.	Corrections for— Tempera-ture.	Corrections for— Density.	Corrections for— Clock-rate.	Corrections for— Flexure.	Reduced Time of Swing in Sidereal Seconds.
								August 13.								
	a.m.	s.	′	′	° C.	° C.										
5	10·45	31·8450	22·0	15·5	+3·14	+·08	739·3	−2·6	0·958	0·5079758	−10	− 142	−617	− 8	−25	0·5078956
21	11·25	27·1481	14·9	10·9	+3·26	+·13	739·5	−2·6	0·958	0·5093815	− 4	− 158	−617	− 8	−33	0·5092995
7	12·10	31·9315	15·2	11·0	+3·40	+·16	739·6	−2·6	0·958	0·5079538	− 5	− 167	−617	− 8	−25	0·5078716
	p.m.															
5	11·10	31·8068	21·2	15·0	+4·96	+·06	736·1	−2·6	0·947	0·5079855	− 9	− 225	−610	− 2	−25	0·5078984
21	12·00	27·1326	14·1	9·2	+4·96	−·04	735·8	−2·6	0·947	0·5093870	− 4	− 242	−610	− 2	−33	0·5092979
7	0·45	31·9076	14·4	10·0	+4·86	−·16	735·6	−2·6	0·947	0·5079599	− 4	− 238	−610	− 2	−25	0·5078720
								August 14.								
	a.m.															
5	5·15	31·8402	21·5	15·1	+3·22	−·28	735·4	−2·6	0·953	0·5079770	− 9	− 146	−614	+ 3	−25	0·5078979
21	6·00	27·1539	19·2	14·2	+3·00	−·16	735·4	−2·6	0·954	0·5093795	− 8	− 146	−614	+ 3	−33	0·5092997
7	6·45	31·9491	18·5	13·2	+2·82	−·19	735·5	−2·6	0·954	0·5079494	− 7	− 138	−614	+ 3	−25	0·5078713
	p.m.															
5	5·40	31·8218	22·2	15·6	+4·13	+·18	731·7	−2·6	0·944	0·5079817	−10	− 189	−608	+ 6	−25	0·5078991
21	6·24	27·1272	20·4	14·8	+4·33	+·22	731·2	−2·6	0·942	0·5093889	− 9	− 211	−607	+ 6	−33	0·5093035
7	7·30	31·9120	18·6	13·1	+4·75	+·37	730·7	−2·6	0·940	0·5079587	− 7	− 233	−605	+ 6	−25	0·5078723
								August 15.								
	a.m.															
5	10·00	31·8652	21·9	18·8	+1·95	+·28	731·1	−2·6	0·951	0·5079706	−11	− 89	−612	+ 9	−25	0·5078982
21	10·50	27·1638	20·2	15·0	+2·24	+·26	731·7	−2·6	0·950	0·5093760	− 9	− 109	−612	+ 9	−33	0·5093006
7	11·30	31·9548	18·4	13·0	+2·53	+·33	732·4	−2·6	0·950	0·5079479	− 7	− 124	−612	+ 9	−25	0·5078720
	p.m.															
5	6·42	31·8129	30·4	21·4	+4·43	−·04	739·4	−2·6	0·954	0·5079839	−18	− 201	−614	+ 6	−25	0·5078987
21	7·30	27·1379	20·2	13·8	+4·41	+·01	739·4	−2·6	0·954	0·5093851	− 8	− 215	−614	+ 6	−33	0·5092987
7	8·15	31·9280	18·6	13·2	+4·45	+·08	739·6	−2·6	0·954	0·5079547	− 7	− 216	−614	+ 6	−25	0·5078691

TABLE XXXIX (continued).

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing. Beginning.	Amplitude of Swing. End.	Temperature. Mean.	Temperature. Δt.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for— Amplitude.	Corrections for— Temperature.	Corrections for— Density.	Corrections for— Clock-rate.	Corrections for— Flexure.	Reduced Time of Swing in Sidereal Seconds.
								August 16.								
	a.m.	s.	′	′	° C.	° C.										
5	10·00	31·8347	26·1	18·1	+4·18	—·09	735·0	—2·6	0·949	0·5079784	—13	— 189	—611	+ 2	—25	0·5078948
21	10·50	27·1344	20·1	15·1	+4·10	—·07	735·6	—2·6	0·950	0·5093864	— 9	— 200	—612	+ 2	—33	0·5093012
7	11·35	31·9284	18·6	13·1	+4·08	+·01	736·1	—2·6	0·951	0·5079546	— 7	— 200	—612	+ 2	—25	0·5078704
	p.m.															
5	5·40	31·8171	25·2	17·9	+4·85	+·19	743·6	—2·6	0·957	0·5079829	—13	— 220	—616	+ 25	—25	0·5078980
21	6·20	27·1239	20·2	15·4	+5·00	+·09	744·3	—2·6	0·958	0·5093901	— 9	— 244	—617	+ 25	—33	0·5093023
7	7·30	31·9171	18·5	13·0	+5·14	+·06	745·2	—2·6	0·959	0·5079574	— 7	— 252	—618	+ 25	—25	0·5078697
								August 17.								
	a.m.															
5	10·12	31·8656	25·4	17·9	+3·14	+·10	750·9	—2·6	0·973	0·5079705	—13	— 142	—627	+ 48	—25	0·5078945
21	11·00	27·1591	20·5	15·4	+3·23	+·08	751·4	—2·6	0·973	0·5093777	— 9	— 157	—626	+ 48	—33	0·5093000
7	11·42	31·9621	17·5	12·5	+3·33	+·10	751·8	—2·6	0·973	0·5079461	— 6	— 163	—627	+ 48	—25	0·5078688
	p.m.															
5	7·00	31·8188	28·5	18·8	+4·98	+·22	752·6	—2·6	0·968	0·5079824	—15	— 226	—624	+ 45	—25	0·5078979
21	7·40	27·1261	20·5	15·5	+5·16	+·12	752·5	—2·6	0·968	0·5093893	— 9	— 253	—623	+ 45	—33	0·5093020
7	8·20	31·9113	17·9	12·9	+5·30	+·13	752·3	—2·6	0·967	0·5079589	— 6	— 260	—623	+ 45	—25	0·5078720

Table XLIII.—Christchurch, 1913.

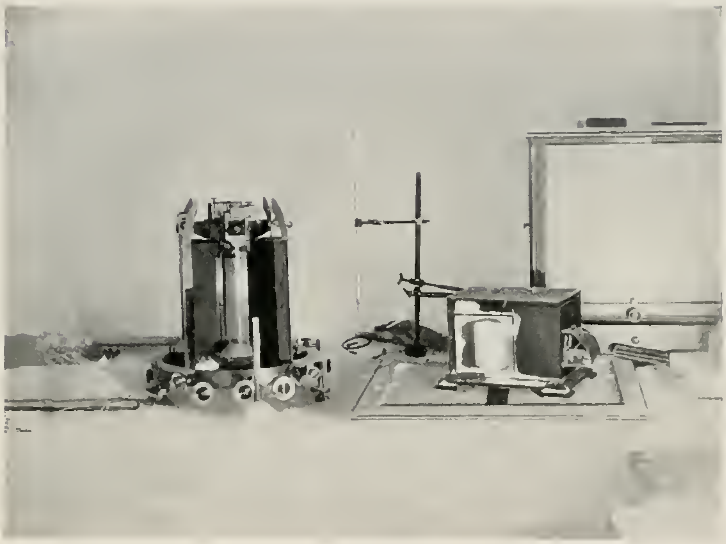
Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing. Beginning.	Amplitude of Swing. End.	Temperature. Mean.	Temperature. Δt.	Percentage Humidity.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for— Amplitude.	Corrections for— Temperature.	Corrections for— Density.	Corrections for— Clock-rate.	Corrections for— Flexure.	Reduced Time of Swing in Sidereal Seconds.
									March 2.								
	a.m.	s.	′	′	° C.	° C.											
21	10·25	25·3294	18·7	14·9	+15·69	−·01	74	760·5	−3·7	0·946	0·5100687	− 8	− 765	−609	+144	−46	0·5099403
5	11·15	29·4013	17·3	12·1	+15·69	·00	74	760·2	−3·7	0·945	0·5086501	− 6	− 711	−609	+144	−50	0·5085269
7	12·25	29·4516	19·9	14·1	+15·70	+·01	74	759·7	−3·7	0·945	0·5086351	− 8	− 770	−609	+144	−50	0·5085058
	p.m.																
7	3·45	29·4552	19·4	14·0	+15·71	·00	74	758·4	−3·7	0·943	0·5086340	− 8	− 771	−607	+144	−50	0·5085048
5	4·25	29·4052	18·2	13·0	+15·70	−·01	74	758·4	−3·7	0·943	0·5086490	− 7	− 711	−607	+144	−50	0·5085259
21	5·15	25·3236	18·4	14·6	+15·72	+·01	74	758·4	−3·7	0·943	0·5100711	− 8	− 766	−607	+144	−46	0·5099428
									March 3.								
	a.m.																
21	10·00	25·3322	20·8	15·8	+15·33	·00	73	763·8	−3·6	0·951	0·5100676	− 9	− 747	−612	+144	−46	0·5099406
5	10·40	29·4108	17·5	12·6	+15·33	·00	73	763·9	−3·6	0·951	0·5086473	− 6	− 694	−612	+144	−50	0·5085255
7	11·25	29·4578	19·4	14·4	+15·33	·00	73	764·0	−3·6	0·952	0·5086333	− 8	− 752	−613	+144	−50	0·5085054
	p.m.																
7	3·00	29·4595	19·3	14·0	+15·35	·00	76	765·0	−3·7	0·953	0·5086327	− 8	− 753	−614	+144	−50	0·5085046
21	3·40	25·3367	20·1	16·3	+15·36	+·01	76	765·0	−3·7	0·953	0·5100657	− 9	− 749	−614	+144	−46	0·5099383
5	4·25	29·4093	18·4	12·8	+15·38	+·02	76	765·0	−3·7	0·953	0·5086477	− 7	− 697	−614	+144	−50	0·5085253

TABLE L.—Wellington, 1913.

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing.		Temperature.		Percentage Humidity.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for—					Reduced Time of Swing in Sidereal Seconds.
			Beginning.	End.	Mean.	Δt.						Amplitude.	Tempera-ture.	Density.	Clock-rate.	Flexure.	
									March 17.								
	p.m.	s.	′	′	° C.	° C.											
5	9·20	29·3818	20·1	14·1	15·10	—·01	96	744·6	—4·6	0·923	0·5086560	— 8	— 684	—594	+706	—20	0·5085960
21	10·00	25·3251	15·6	11·6	15·09	—·01	96	744·5	—4·6	0·923	0·5100705	— 5	— 735	—594	+706	—30	0·5100047
7	10·50	29·4357	19·7	14·6	15·08	—·01	96	744·4	—4·6	0·923	0·5086398	— 8	— 740	—594	+706	—20	0·5085743
									March 18.								
	a.m.																
7	9·50	29·4435	18·4	13·8	14·92	—·01	96	746·0	—4·6	0·925	0·5086375	— 7	— 732	—596	+706	—20	0·5085726
21	10·35	25·3251	15·8	12·0	14·92	+·01	96	746·4	—4·6	0·925	0·5100705	— 5	— 727	—596	+706	—30	0·5100053
5	11·15	29·3753	19·8	14·8	14·92	·00	96	746·7	—4·6	0·926	0·5086579	— 8	— 676	—596	+706	—20	0·5085985
	p.m.																
5	7·45	29·3749	19·7	14·0	15·11	·00	96	747·1	—4·6	0·926	0·5086580	— 8	— 684	—596	+704	—20	0·5085976
21	8·26	25·3224	15·8	12·2	15·11	—·01	96	748·1	—4·6	0·927	0·5100716	— 5	— 736	—597	+704	—30	0·5100052
7	9·10	29·4403	21·2	15·2	15·10	—·01	96	747·4	—4·6	0·926	0·5086385	— 9	— 741	—596	+704	—20	0·5085723
									March 19.								
	a.m.																
7	10·20	29·4316	20·7	14·6	15·20	·00	96	750·4	—4·6	0·929	0·5086411	— 9	— 746	—598	+704	—20	0·5085744
21	10·55	25·3190	14·8	10·7	15·20	·00	96	750·2	—4·6	0·929	0·5100729	— 4	— 741	—598	+704	—30	0·5100060
5	11·30	29·3693	19·9	14·2	15·20	·00	96	750·0	—4·6	0·929	0·5086597	— 8	— 689	—598	+704	—20	0·5085986
	p.m.																
5	8·20	29·3825	19·4	13·9	15·22	—·04	96	750·1	—4·6	0·929	0·5086558	— 8	— 689	—598	+727	—20	0·5085970
21	9·00	25·3268	15·1	11·0	15·19	—·03	96	750·1	—4·6	0·929	0·5100698	— 4	— 740	—598	+727	—30	0·5100053
7	9·40	29·4475	23·5	17·2	15·16	—·02	96	749·8	—4·6	0·929	0·5086363	—11	— 744	—598	+727	—20	0·5085717

Table LV.—Melbourne, 1913.

Pendulum Number.	Time.	Coincidence Interval.	Amplitude of Swing.		Temperature.		Percentage Humidity.	Pressure.	Correction for Humidity.	Relative Density of Air.	Time of Swing (Observed).	Corrections for—					Reduced Time of Swing in Sidereal Seconds.
			Beginning.	End.	Mean.	Δt.						Amplitude.	Temperature.	Density.	Clock-rate.	Flexure.	
		s.	′	′	° C.	° C.			April 1.								
	a.m.																
5	9·45	28·9267	17·5	12·9	+16·31	·00	84	767·6	−4·3	0·947	0·5087945	− 6	−739	−610	+162	−27	0·5086725
21	10·28	24·9941	16·1	12·3	+16·31	+·01	84	767·6	−4·3	0·947	0·5102065	− 5	−795	−610	+162	−34	0·5100783
7	11·09	28·9891	21·2	16·6	+16·32	+·01	84	767·6	−4·3	0·947	0·5087753	−10	−801	−610	+162	−27	0·5086467
	p.m.																
7	9·25	28·9883	17·5	12·7	+16·52	−·05	83	767·8	−4·4	0·947	0·5087755	− 6	−811	−610	+168	−27	0·5086469
21	10·04	24·9941	17·5	13·2	+16·48	−·03	84	767·8	−4·4	0·947	0·5102065	− 6	−803	−610	+168	−34	0·5100780
5	10·44	28·9280	17·5	12·3	+16·48	+·02	84	767·9	−4·4	0·947	0·5087941	− 6	−747	−610	+168	−27	0·5086719
									April 2.								
	a.m.																
5	9·30	28·9237	18·2	13·2	+16·36	−·01	83	768·1	−4·3	0·948	0·5087955	− 7	−741	−610	+161	−27	0·5086731
21	10·10	24·9933	17·6	13·6	+16·37	+·01	82	768·1	−4·3	0·948	0·5102069	− 7	−798	−610	+161	−34	0·5100781
7	10·49	28·9901	17·5	12·8	+16·38	+·03	82	768·1	−4·3	0·948	0·5087750	− 6	−804	−610	+161	−27	0·5086464
	p.m.																
7	9·25	28·9846	17·5	12·8	+16·56	−·01	(85)	766·9	−(4·5)	0·946	0·5087767	− 6	−812	−609	+154	−27	0·5086467
21	10·04	24·9859	17·6	13·6	+16·57	+·01	(85)	766·9	−(4·5)	0·946	0·5102100	− 7	−808	−609	+154	−34	0·5100796
5	10·43	28·9204	18·3	13·2	+16·60	+·04	(85)	767·1	−(4·5)	0·946	0·5087965	− 7	−752	−609	+154	−27	0·5086724
									April 3.								
	a.m.																
5	9·47	28·9138	18·4	13·2	+16·51	·00	89	767·1	−4·6	0·946	0·5087985	− 7	−748	−609	+135	−27	0·5086729
21	10·26	24·9858	16·8	12·9	+16·51	+·01	86	767·1	−4·6	0·946	0·5102100	− 6	−805	−609	+135	−34	0·5100781
7	11·07	28·9809	19·8	14·4	+16·53	+·02	87	767·0	−4·6	0·946	0·5087778	− 8	−811	−609	+135	−27	0·5086458
	p.m.																
7	8·44	28·9766	15·4	11·7	+16·88	−·04	88	768·9	−4·7	0·947	0·5087791	− 5	−828	−610	+155	−27	0·5086476
21	9·24	24·9823	18·8	14·5	+16·85	·00	88	768·9	−4·7	0·947	0·5102115	− 8	−821	−610	+155	−34	0·5100797
5	10·05	28·9259	18·3	13·1	+16·85	·00	88	768·9	−4·7	0·947	0·5087948	− 7	−763	−610	+155	−27	0·5086696



[*Photo by Wright.*

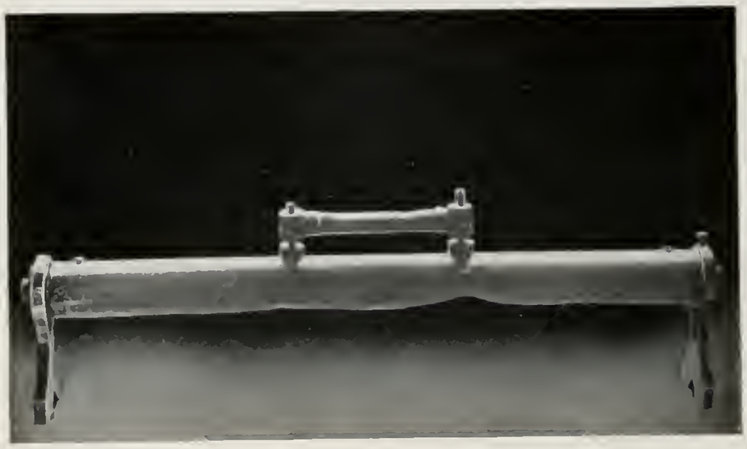
Pendulum Apparatus set up in Cave.

[*Photo by Ponting.*

Clock "S.C." and Telephone in Hut.

[*Photo by Ponting.*

Transit Instrument in use.



[*Photo by Wright.*

Converted Striding Level.